THE UNIVERSITY OF ALBERTA

PLEISTOCENE GEOLOGY OF THE OVANDO VALLEY, MONTANA

by

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER OF SCIENCE

DEPARTMENT OF GEOGRAPHY

EDMONTON, ALBERTA

FALL, 1971

Abstract

The glacial and associated fluvial deposits of the former Monture Creek Glacier in the Ovando Valley of Montana are examined in order to establish a glacial chronology for this locality. Sediments in one section of the valley were studied by means of textural analysis to determine depositional environment. Morainal deposits were dated through the use of relative-age dating techniques such as soil depth, depth of leaching, topographic expression, destruction of lakes by lip erosion and filling, and weathering of the surface boulders. Till fabric analysis was carried out in morainic materials where the source of the glacier depositing the moraine was in question.

Based on the relative-age data, the moraines deposited by the former Monture Creek Glacier are divided into three groups. The oldest, Monture Hill Glaciation, is expressed as a sheet-like deposit on the summit of the hill for which it was named. Moraines of the Blackfoot River Glaciation are younger than the Monture Hill deposit and are most prominantly displayed near the Blackfoot River. Evidence suggests that this glaciation may be divided into two stades. The youngest glacial deposits of the Ovando Valley were laid down during the Monture Creek Glaciation. There is evidence

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Based on the relative-age data, the moraines deposited by the former Monture Creek Glacier are divided into three groups. The oldest, Kozenza Hill Glaciation, is expressed as a sheet-like deposit on the summit of the hill for which it was named. Moraines of the Blackfoot River Glaciation are younger than the Kozenza Hill deposit and are most prominently displayed near the Blackfoot River. Evidence suggests that this glaciation may be divided into two stades. The youngest glacial deposits of the Ovando Valley were laid down during the Monture Creek Glaciation. There is evidence

that this glaciation may be composed of three stades. These three sets of moraines have been correlated with the glaciations proposed by Blackwelder (1915) - the Monture Hill moraine being pre-Bull Lake in age, the Blackfoot River being Bull Lake in age, and the Monture Creek moraines being Pinedale in age. Features resulting indirectly from the occupation of the Ovando Valley by the former Monture Creek Glacier are also briefly discussed.

Acknowledgments

Numerous individuals and institutions have provided assistance in the preparation of this thesis. The staff of the U.S. Soil Conservation Service in Missoula, Montana, were helpful in the study of the soils, as was Thomas Nimlos of the School of Forestry at the University of Montana. Richard Konizeski, Professor of Hydrogeology at the University of Montana, aided in the interpretation of Tertiary deposits in the Ovando Valley. The U.S. Geological Survey in Washington, D.C., provided the unpublished geologic maps of the study area. The U.S. Bureau of Land Management loaned several aerial photographs of the Monture Hill section of the Ovando Valley. Dr. C.B. Beaty made several valuable suggestions on how to conduct the field survey. Dr. D. Winston of the Department of Geology at the University of Montana arranged for the use of laboratory facilities to conduct the analysis of sediment samples. Special thanks are due to Dr. John Shaw of the Department of Geography at the University of Alberta for supervising the thesis and providing many valuable suggestions in its preparation. G. Lester greatly aided in the preparation of the maps and illustrations.

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INTRODUCTION

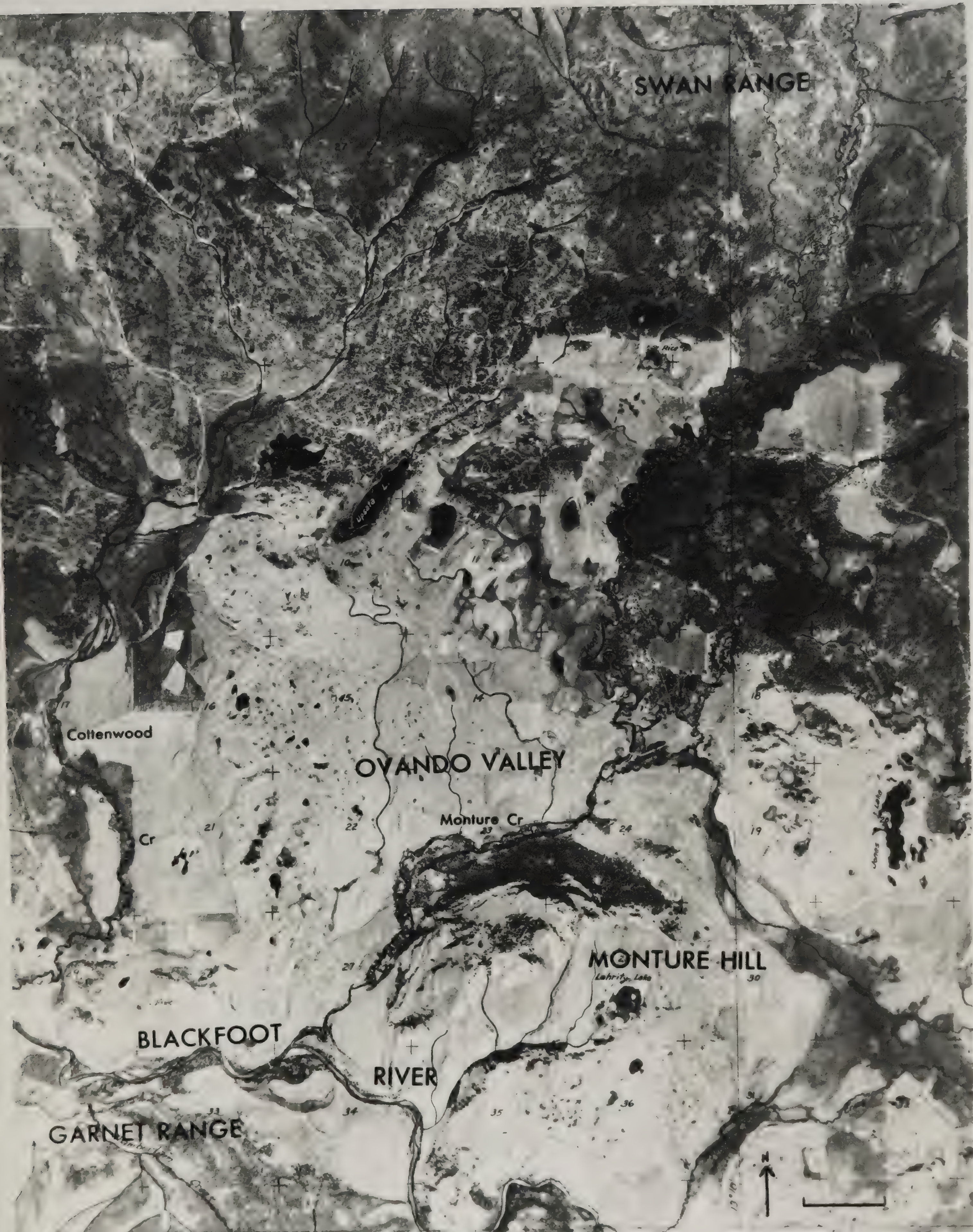
Western Montana holds many interesting and significant Pleistocene glacial deposits in its system of valleys and mountain ranges. At present, little comprehensive research has been done on these features. Consequently, the sequence of events, especially in the smaller valleys, remains obscure in comparison with the eastern and mid-western parts of the United States. One such valley, that of the Ovando basin or lower Monture Creek, is an example. It is the purpose of this thesis to examine the former Monture Creek Glacier deposits and to illustrate the landforms associated with these glacial deposits.

After the various moraines and associated alluvial deposits have been diciphered and discussed, the relationship of these landforms to other features of similar origin in the northern Rocky Mountains will be presented. Through this study it is hoped that the Pleistocene History of one segment of Western Montana will be revealed, thus aiding in the eventual construction of a complete sequence of events of the Pleistocene in the state of Montana and the northern Rocky Mountains.

PHYSIOGRAPHIC SETTING

The study area is situated in what is locally known as the upper Blackfoot River Valley. However, in order to avoid confusion, the name Ovando Valley will be applied as the upper Blackfoot River Valley is actually a series of small interconnected basins. These valleys are drained by the Blackfoot River, a tributary of the Clark Fork which empties into the Columbia River. Just above the eastern end of the valley the river divides into Nevada Creek, coming from the southeast, and the North Fork of the Blackfoot River, originating from the northeast. Garnet Range forms the southern boundary of the valley and the Swan Range makes up the northern limit (Fig. 1).

Both the Swan and Garnet Ranges can be classified as fault-black mountains. The Swan Range fault runs along the base of the mountains at the extreme northern end of Ovando Valley (Diess, 1947). Elevations of these mountains reach over 9000 feet (2700 meters) at the divide. Garent Range on the south is considerably lower in elevation, averaging 6000-6500 feet (1800-1950 meters). Pardee (1918) suggests that the mountains may have been formed by the dissection of a peneplain uplifted during the early Tertiary. Monture Hill (Fig. 1) seems to have once been a part of the range but since has been separated from it by the Blackfoot River. This separation will be discussed more fully later.



SWAN RANGE
Upsata L.
Rice
Cottonwood
Cr
OVANDO VALLEY
Monture Cr
MONTURE HILL
Lehrity Lake
Jones Lake
BLACKFOOT
RIVER
GARNET RANGE
R.D.W.
N

The Swan Range supported many glaciers near its divide during the Pleistocene whereas the Garnet Range appeared to be relatively free from glacial ice. The upper part of the former range is thoroughly dissected by cirques and glaciated valleys, many of which contain ice scoured lake basins and hanging valleys. Only in the larger canyons, however, were the glaciers of sufficient size to fill the entire length of the valley and flow out into Ovando Valley. None of the small tributary canyons adjacent to Monture Creek appear to have been glaciated in their lower courses. In contrast to the Swan Range, Garnet Range (Fig. 1) supported little ice during the Pleistocene. No cirques or U-shaped valleys are discernable, nor was any morainal debris evident when the writer examined the area. It seems that the lower altitude of this range was not conducive to ice formation. Had any ice existed during this time it must have been confined to small patches near the summits of the highest peaks.

Thickness of the moraines and fluvial deposits does not exceed 120 feet in most places in the valley. One local well record reveals that Tertiary Lake Beds lie below this thickness of superficial deposits in the central part of the valley (R. Konizeski, personal communication, 1969). Near the higher portions of the southern part of

the valley, these lake bed deposits and quartzite beds reach the surface level. Monture Hill (Fig. 1) exhibits excellent exposures of these materials.

The former Monture Creek Glacier was not the only ice lobe to occupy the valley, although it covered the largest area in it. Several times during the Pleistocene, glaciers entered the valley through Cottenwood and North Fork Canyons. At the maximum extent of glaciation ice completely covered the valley floor and flowed out through the canyon west of Monture Hill, the present course of the Blackfoot River (Fig. 1). In the later stades each lobe remained distinctly separate, as evidenced by the individual lateral and terminal moraines. The Monture lobe was unique in that it spread out into a broad ice tongue approximately five times the width of the confining canyon. The pattern of moraines presented in figure 14 gives some idea of the lateral spreading of the ice tongue. Cottenwood and North Fork glaciers changed very little in width upon emerging from their canyons.

In spite of its relatively high altitude (mean elevation of 4100 feet - 1220 meters), the Ovando Valley has a remarkably dry climate. Mean annual precipitation is 17 inches - 43 cm (U.S. Weather Bureau) which is distributed fairly evenly throughout the year. Short grasses predominate on the main valley floor, mainly in response to the low effective precipitation, and a few trees grow on the wetter north facing slopes of the moraines. Soils are of the Chestnut type (Blinn and Habeck, 1960).

TECHNIQUES

Three major techniques were employed in this study to decipher the sequence of glacial events resulting from the deposition by the former Monture Creek Glacier. These include texture analysis, relative-age dating, and till fabric analysis. Textural analysis can be used to determine depositional environment of sediments and from this can be deduced the environmental sequence (Doeglas, 1962). Relative-age dating can be used to determine the number of episodes of glaciation in an area (ex. Blackwelder, 1931). Till fabric can be employed to elucidate the source of a moraine where two glaciers occupied the same area at different times during an episode of glaciation (ex. Glen, 1957).

Sediment Analysis

Ideally, by studying a complete section of deposits in a region, it is possible to obtain a very accurate picutre of the glacial events. In reality, such sections are rarely available and much of the stratigraphy is not revealed, even in widely scattered exposures. Such was the case in the Ovando Valley. One exposure did permit an analysis of a part of the chronology of Pleistocene depositional history. This section was situated at the southern base of Monture Hill, adjacent to the Blackfoot River (Fig. 1). The river has recently changed its course and is now eroding into the sediments flanking the hill, of which the exposure is a part. Sediments in this

section represent not only those derived from the former Monture Creek Glacier and its meltwater, but also those from the former North Fork Glacier. Consequently, interpretation of the source of this material was difficult.

The exposure was first divided into similar stratigraphic units. This division was based on the homogeneity of the material in each section. For example, a section of varved clay was classified as a bed. In another instance, alternating coarse and fine gravel was separated into a bed. Each section or layer had to have some degree of similarity both in texture and stratification. If a relatively coarse layer of gravel occurred in a sand layer, and this was the only one present, it was divided into a separate unit. Next, each bed or stratigraphic unit was measured to the nearest centimeter with a steel tape. After the thickness of each bed was determined, a representative sample was taken for laboratory analysis. Size of the sample varied, depending on size of the individual particles. Weight of each sample ranged from 75 grams for the finest sands and clays to over 1000 grams for the coarse gravels.

Each sample taken in this exposure was subjected to a sieve analysis. Various sieve sizes were used, depending on material size. Phi values and equivelant mm values of the sieves used included: -5 (40), -4 (16), -3 (10), -2 (4), -1.25 (2.38), 0.5 (0.71), 1.0 (0.50), 1.5 (0.35), 2.0 (0.25), 3.0 (0.125), 3.5 (0.088), and 4.0 (0.0625). A 25 gram sample

was separated into various size groups though these sieves. The cumulative % weight was recorded on each of the cumulative frequency graphs where the ordinate represents the cumulative frequency and the abscissa the phi diameter particle size (ex., see fig. 6). If more than 5% of the material passed through the 4.0 phi diameter sieve it was further divided according to size by means of pipette analysis. This method which involves the settling rates of materials in water is outlined in Twenhofel and Tyler (1941).

From the cumulative frequency graphs, the graphic mean, graphic standard deviation, and skewness were calculated. These values not only provide a quantitative method for describing the sediment but also give a valuable insight into the depositional environment. The formula for each of these parameters is presented below (Folk and Ward, 1957):

$$\text{Graphic Mean} = \frac{\phi16 + \phi50 + \phi84}{3}$$

$$\text{Graphic Standard Deviation} = \frac{\phi84 - \phi16}{4} + \frac{\phi95 - \phi5}{6.6}$$

$$\text{Skewness} = \frac{\phi16 + \phi84 - 2\phi50}{2(\phi84 - \phi16)} + \frac{\phi5 + \phi95 - 2\phi50}{2(\phi95 - \phi5)}$$

where ϕ represents phi value. The $\phi50$ defines the size separating the sample into two equal halves by weight. The $\phi16$ gives an average for the coarsest third of the sample and the $\phi84$ gives an average for the finest third. The above formula gives a resonably accurate method for

describing the mean of the sample. The formula for graphic standard deviation describes the sorting quality of the sample. The amount of deviation from the mean by the extremes (Ø95 and Ø5) can be readily determined to describe this quality of the sample. Amount of skewness is indicated by the departure of the mean from the median (Ø value which has an equal number of sizes below and above it). Skewness indicates whether there is an abundance of coarse or fine material, as compared to the mean of the sample.

Relative-Age Dating

Relative-age dating techniques have been successfully applied in several studies to trace the sequence of events of the Pleistocene. Blackwelder (1931) in his classic study of moraines in the Sierra Nevada Range of California developed a criteria for such determinations. Sharp (1960) working in the same area expands somewhat on these methods. Birman (1964) applied Blackwelder's techniques with considerable success to the Trinity Alps in northern California. Sharp (1969) attempts to refine some of Blackwelder's methods in a study conducted in the area of his previous work (1960), but his success in this endeavor is somewhat limited. His data does not differ greatly enough for the moraines of different age groups to enable him to draw any firm conclusions. Five techniques were chosen for use in this study - topographic expression of the moraines, soil development, topographic position, weathering of surface boulders, and destruction of lakes by lip erosion or filling.

Soil Development. Degree of soil development proved to be one of the most useful methods applied in the Ovando Valley. Soil depth was assumed to be a function of time with the other controls - climate, parent material, topographic position, and vegetation playing secondary roles. This assumption was justified by the fact that sampling was carried out in a small and relatively uniform environment. Variations in soil depth arising from the last three controls could be minimized by selective sampling. For example, comparison of the soils was made only on genetically similar material, thus reducing the influence of parent material. Soils on lateral moraines were not compared directly with those on hummocky disintegration deposits. The former had a higher proportion of coarse material (boulders) which would delay the soil forming processes (longer time required for stones to be weathered into soil mineral components). The latter had an unusually high proportion of silts and clays which are more easily weathered. The influence of topographic position was reduced somewhat by confining the sampling to the east or west, and sometimes south exposures. From experience it was noted that the greatest variation in soil depth occurred between these three exposures and the north-facing slopes, the latter having a greater soil depth (a response to the wetter environment). Whenever possible, sampling was confined to areas supporting the same type of vegetation. Soil depth was greater for sections covered by forest than it was for grassland. The grassland environment provided most of the sampling sites.

Three characteristics of the soil were measured - depths of the A horizon, B horizon (if present), and leaching. Jack Parcell, soil scientist for the U.S. Soil Conservation Service, conducted a study on the type of soil found in the Ovando Valley. His analysis was made on an area approximately five miles from this area but the general results are applicable. In his unpublished study, he states that the A horizon is made up of dark gray, gravelly loam with a moderate medium and fine granular structure, slightly hard, very friable, and non-plastic and non-sticky. The color of the A horizon is dark gray with a clear smooth boundary between it and the underlying B horizon. The B horizon is pale brown in color, very gravelly, with a medium and fine blocky structure. This loam is very friable, non-sticky and non-plastic.

One exposure through an entire mound in the hummocky disintegration moraine indicated the importance of the soil measurement site with respect to position on the mound. Figure 2 is a diagrammatic representation, based on this cross section. As can be seen in the diagram, soil depth was lower on the top of the mound than for the sides. This lower depth may be a response to the drier environment (winter snow blown off the crest by the prevailing winds). In order to minimize the influence of position, all readings were confined to the upper 50% of the slope. Measurements on the crests were included since, as the diagram illustrates, differences in depth between this sector and the upper portions

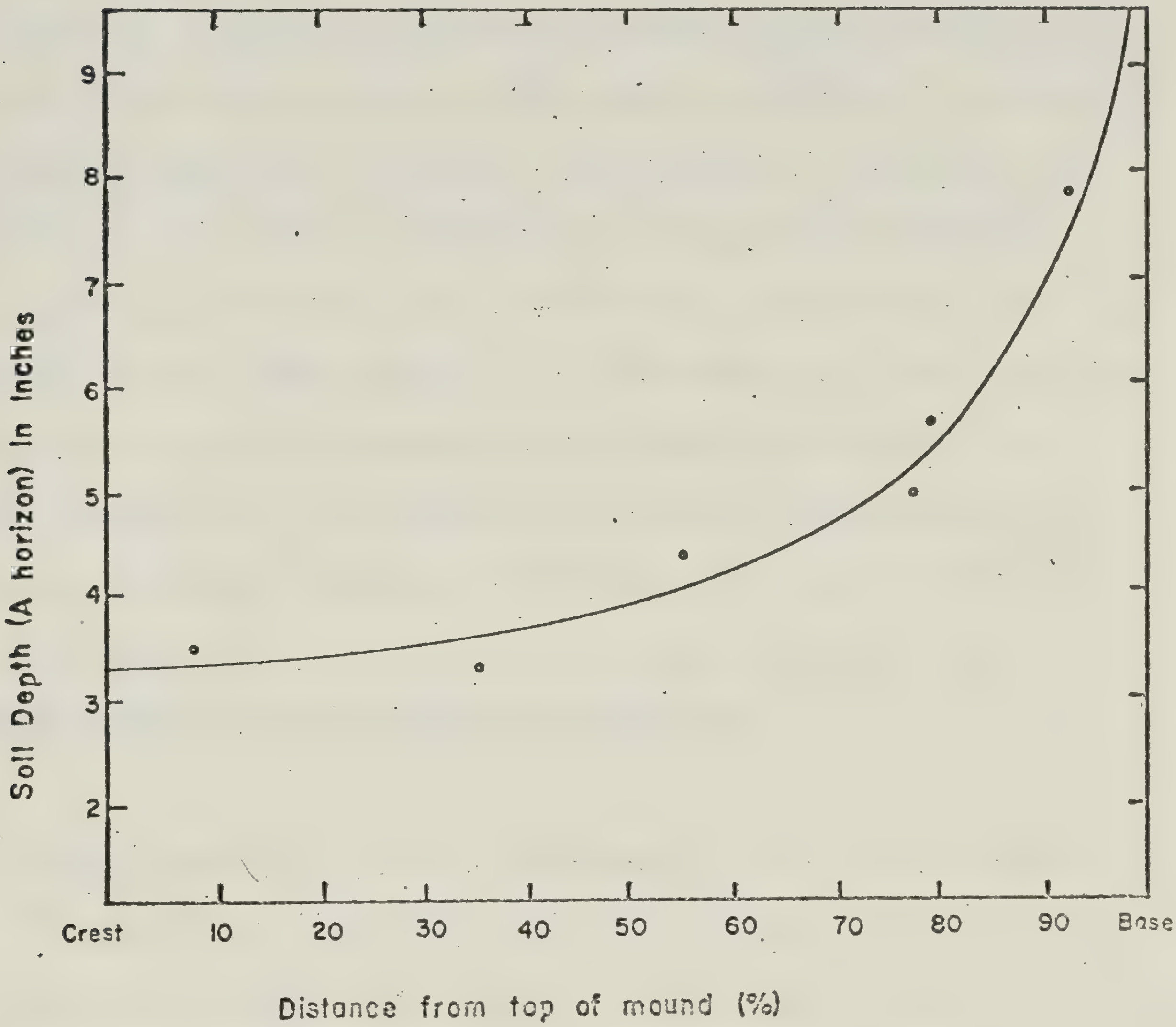


Figure 2. Variation of soil depth (A horizon) with position on a morainal mound. Circles indicate actual measurements on one road cut. Numerous field observations follow this same general pattern.

of the slope were not great enough to significantly alter the mean values.

Depth of leaching followed the same general pattern as did soil depth but with two additional variations. In the more compact boulder-clay till, the degree of leaching was less than in the lateral moraines. Also, since leaching cannot proceed past the local water table, its depth is shallower in the depressions. By following the same sampling as practiced in soil measurements, variations caused by factors other than time could be reduced or eliminated to give more constant results. Depth of leaching in this area is marked by a thin white coating of calcium carbonate on rocks at various depths below the surface.

Topographic Expression of the Moraines. With the passage of time, the absolute relief of a moraine is reduced by running water and mass wasting processes. Older moraines have a more subdued topographic expression and lower mean slope angle as compared to the genetically younger moraines. When comparing the surface expression of two moraines formed by similar depositional mechanisms, the values can be logically compared. This comparison cannot be made on moraines of different origins (ex. terminal and hummocky disintegration moraines).

Slope angles and profiles were taken on various moraine types. When taking slope angles, only the west-facing straight

segment of a mound adjoining a depression (kettle) was measured. By keeping to one aspect of the mound, variations due to micro-climate could be eliminated from the values. Slope variation with aspect is quite important, as evidenced by Blinn and Habeck's (1960, p. 10) vegetational studies in the area. They found that the average inclination of the north-facing segments was 7.6 degrees greater than the south-facing parts.

When choosing sides, an attempt was made to follow a straight line through the moraines, taking the reading on the first ten west-facing slopes encountered. Slope angles were read to the nearest degree with an Abney level and were taken at the foot of the straight segment. From these readings the mean value of west-facing slopes for the entire moraine could be approximated.

<u>Destruction of Lakes by Lip Erosion or Filling</u>. The "knob and kettle" topography of the Ovando Valley afforded an excellent opportunity to compare degrees of filling of the small basins by material derived from the adjacent slopes. Due to the relatively dry climate, an integrated drainage system has not been established on the moraines. In the younger sets, none of the basins are interconnected by channels. Any material deposited in the basins would have had to come from the adjacent slopes.

The degree of filling was not easy to assess quantitatively. It does, however, become quite apparent in the cross-section (Fig. 16). There is a sharp demarkation between partially-filled and filled basins. Those that have been filled are much shallower with floors less concave in profile. Most of the depressions contain little or no water and support a growth of trees. Contrasted with this condition are the younger basins with concave floors and which hold water most or part of the year.

Weathering of Surface Boulders. The weathering conditions of surface boulders is an indication of the duration of exposure to weathering. The weathering rind increases with time unless the boulder changes position on the moraine. Once a moraine becomes stabilized, the chances of boulder movement become less, especially for the larger boulders. Birman (1964) used granite-weathering ratios to differentiate moraines in the Trinity Alps. In this case, the predominance of granite in the source areas of the glaciers provided abundant boulders in the moraines for the application of such techniques. Granite displays the effects of weathering unusually well. A rind on its outer portion contrasts with the fresh unweathered interior of the rock.

After a preliminary survey of the surface boulders in the Ovando Valley, argillite was chosen for the measurements. This rock was readily recognized in the field and displayed

the most pronounced effects of weathering. Initially, it was decided to measure weathering rind depth on twenty-five stones on each set of moraines. It soon became apparent, however, that argillite boulders were rare on the surface of the older moraines. Thus, the number of observations on these deposits is less than on the younger moraines. Contrasts between weathering depths of boulders on the moraines of various ages was so pronounced that the lack of boulders on the older sets presented no problem. Weathered boulders on the younger moraines had a small rind of weathering which was darker in color than the underlying unweathered material. The rock itself was basically sound which contrasted to the condition of boulders on the older moraines which were extensively shattered by frost weathering. On the older stones the frost shattered zones extended to a considerable depth compared to rocks on the younger moraines.

Till Fabric Analysis

The movement of two separate ice lobes into the Ovando Valley from different directions necessitated the use of till fabric analysis to determine the source of deposition. Where the surface form of the moraine clearly indicated the source of the ice, as in the case of lateral and terminal moraines, such analysis was unnecessary. Only where the material was of a questionable source (ground moraine) was this procedure required.

The basic assumption in using till fabric as an indicator of ice source and consequent morainal deposits is that elongated pebbles become aligned with the direction of ice movement. Glen, et. al. (1957, p. 198) noted that objects placed at random in a flowing liquid soon developed a parallel orientation to their long axis, and then, as time proceeds, they slowly develop a transverse orientation if their parallel axial ratio is less than 15 to 1. Interaction of the ice with the bed or across a shear plane can also cause preferred orientation. If these stones are deposited by active ice, their orientation will tend to parallel the ice flow direction. Disturbance of the till after deposition (slumping or solifluction) can alter the orientation of stones in deposits such as hummocky moraines.

Orientations of fifty pebbles in a one foot by one foot square pit were measured and plotted on a rose diagram (Fig. 3). Pebbles with a long to short axis of two to one or more were included in the measurements. Each pit was situated at least five feet below the ground surface level to minimize the effect of agencies such as frost action and burrowing animals which could change orientations of the stones. All measurements were made in ground moraine. In the oldest moraine of the study area, two pits were dug in the space of 30 feet (9 m). Such closeness of sample sites was necessary because of the limited exposure of the till.

GLACIAL CHRONOLOGY

General Statement

The moraines of the former Monture Glacier have been grouped into three catagories, based on relative-age data. The oldest set of these deposits has been assigned to the <u>Monture Hill Advance</u> since the till can be recognized only at that locality. Moraines of the middle advance have been termed <u>Blackfoot River</u> since they are most extensive around the river. Youngest of the three sets is termed <u>Monture Creek</u> because of their extensive distribution around this stream.

Individual moraines within each set have been designated by the letters <u>A</u>, <u>B</u>, or <u>C</u>. A refers to the youngest till and C indicates the oldest with B being intermediate in age. Letters instead of names were chosen for two reasons: (1) lack of any topographic features near the till from which names could be applied and (2) uncertainity as to whether these moraines resulted from separate advances or from a halt in the retreat of the glacier. The second point will be discussed later.

The following discussion will begin with the oldest recognizable till (Monture Hill) and proceed through the youngest deposits and associated features. Stratigraphic analysis will be discussed in the proper chronological order.

Monture Hill Advance

Till from the Monture Hill Glaciation occurs only as thin ground moraine on and adjacent to this upland. The Hill itself is composed of a quartzite core surrounded by Tertiary Lake Bed sediments (Deiss, 1947). The drift overlies both of these beds except on the steep flanks of the hill where it has been removed by erosion. Overriding by ice at one time is indicated by the rounded summit with a steep stoss side (north) and a gentle lee side (south). Part of this configuration could be due to structure; the quartzite beds dip at an angle of 20 degree northeast. However, the essentially flat-lying Tertiary Lake Beds display the same form. Along the ridge crest numerous rounded boulders of quartzite, argillite, sandstone, and diorite mantle the bedrock. The swales on parts of the hill are the only places where the till is of any depth.

Monture Hill at one time was part of the Garnet Range, immediately to the south. Bedrock of the hill and the range is the same, and the outline of the margins of both features coincide remarkably well. On the lower portions between the river and the hill, quartzite underlies the drift-covered benches. In pre-Pleistocene time the Blackfoot River flowed around the northern side of the hill (Alden, 1953). When glaciers from Monture Canyon and the North Fork Vally descended into the valley, the course of the river was forced southward.

Soil on the till is well developed, much more so than on the younger moraines of the valley. On one exposure which occupied the head of a small valley, the A horizon was measured at 28 inches (72 cm) and the B horizon extended 54 inches (139 cm) below the base of the upper horizon. It was not possible to determine depth of leaching. In contrast, soil on the adjacent Tertiary rock had a total depth of 12 inches (31 cm), the A and B horizon each being about 6 inches (15 cm). However, the A zone is better developed compared to the same horizon on the adjacent till. The parent material is not evident in the A horizon of the soil overlying the Tertiary rock and the underlying B zone is more thoroughly weathered than its counterpart on the till.

Apparently, the glaciers advanced as far south as the margin of the Garnet Range (Fig. 1). Monture Hill and the adjacent slopes to the south must have been covered with ice for a considerable length of time. The river trimmed off the projecting spurs of the range (erosion by the advancing ice also aided in the removal) for now a straight dry channel forms the margins of the range southeast of Monture Hill. When the ice withdrew, the river shifted to its present position. It was not able to reoccupy its former course to the north of Monture Hill, probably because of the thick morainal material left behind by the glaciers. Tributaries flowing north from the Garnet Range were diverted to the west (see lower part of figure 1), some cutting new channels in the bedrock.

Alden (1953, p. 106) stated that the availability of an outlet past the Wisconsin glaciers determined the course of the Blackfoot River. To some extent this is true but the primary valley the river now occupies was cut in pre-Pleistocene time. Tertiary sediments cover extensive areas between the summit of the hill and the river. If the present valley had been formed in the early Pleistocene, these sediments would not fill portions of the valley. The valley must be at least Tertiary in age.

The Tertiary sediments are capped by drift of the Monture Hill Glaciation over much of the summit of the hill. Consequently, this position gives a maximum age for glacial drift in the valley. There may be older drift present, but it was found.

Since this study was concerned mainly with moraines of the former Monture Glacier, it was necessary to determine if the till covering Monture Hill was deposited by this glacier or by the former North Fork Glacier which entered the Ovando Valley from the east. To this end, several till fabric analyses were made on a section of drift situated in a small depression south of the summit area. As can be seen from the first rose diagram (Fig. 3A), the long axis of the stones did not follow one direction. Instead, equal numbers of pebbles were aligned in two directions, each direction coinciding with the direction of movement of the two ice lobes. A second

fabric analysis (Fig. 3B) revealed an orientation dominantly in the direction of flow of the Monture Lobe. It is not possible to drawn any conclusions from the available data. The variation of till fabric (up to 45°) and the influence of local topography can cause the variability observed in these two patterns. The data does indicate that either of the glaciers, or both, influenced the orientation. However, it is not possible to determine which glacier deposited the till. Had till of this advance been more extensive, it may have been possible to assign an ice source.

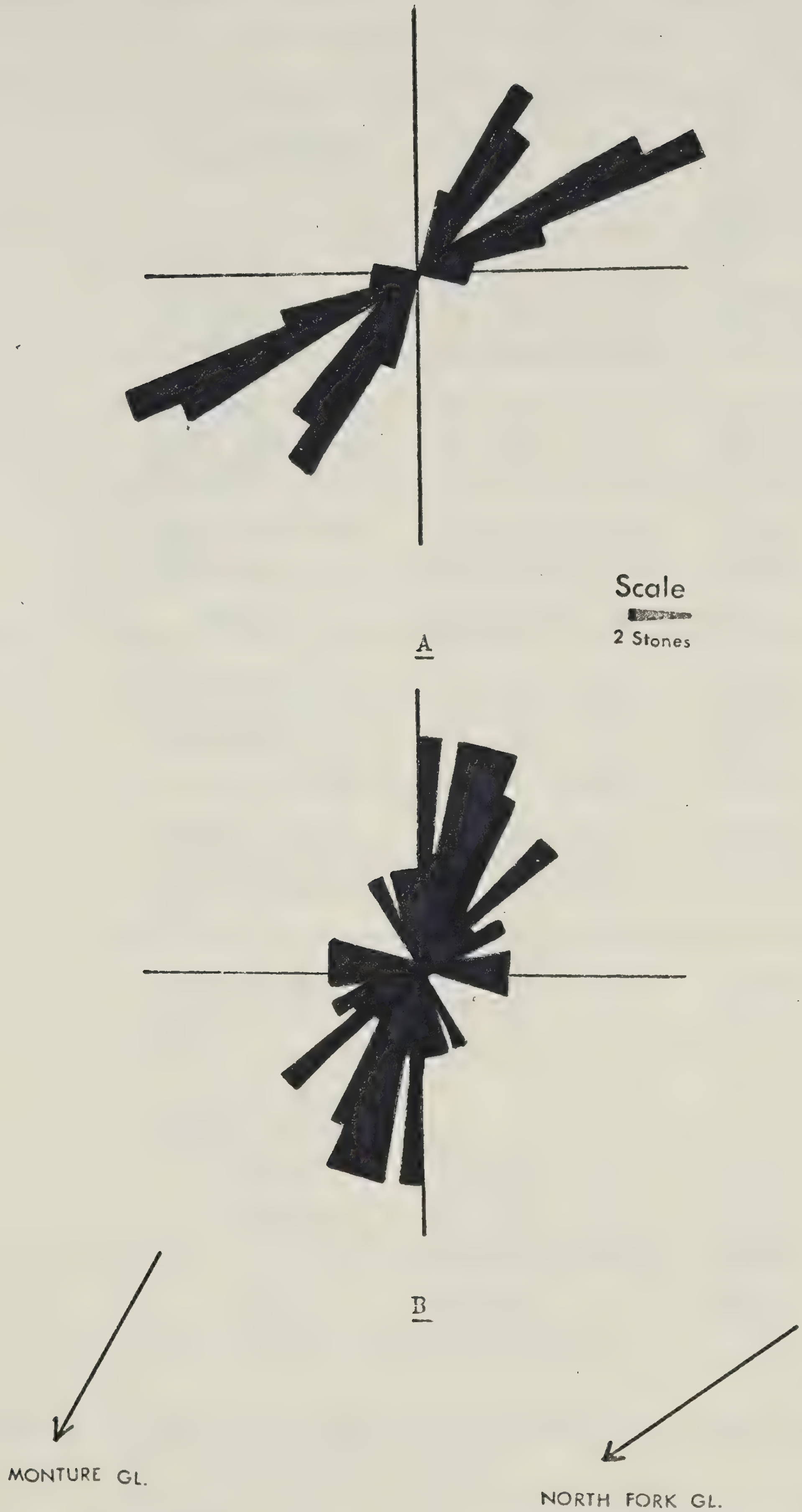


Figure 3. Results of a till fabric analysis conducted on the Monture Hill Moraine.

Glacial Advance	Moraine Segment	Soil Depth A	Soil Depth B	Depth of Leaching
Monture Hill		72 cm	139 cm	----
Blackfoot River	S.E. Monture Hill	44 cm	54 cm	93+ cm
		44 cm	51 cm	97 cm
		46 cm	----	103 cm
		46 cm	----	103 cm
	South of Blackfoot R.	46 cm	51 cm	Greater than 185 cm
		41 cm	46 cm	
		46 cm	50 cm	
	Lateral Moraine West side of Monture Hill	41 cm	----	Greater than 123 cm
		50 cm	----	
		51 cm	----	
	East Side of Valley	44 cm	21 cm	82 cm
		31 cm	29 cm	77 cm
	Mean	44 cm	41 cm	----
Monture Creek	Hummocky Disintegration Moraines	10 cm	----	54 cm
		11 cm	----	47 cm
		8 cm	----	50 cm
		13 cm	----	50 cm
	Lateral and Terminal Moraine east of Monture Hill	13 cm	----	44 cm
		21 cm	----	47 cm
		13 cm	----	47 cm
	Lateral Moraine west of Monture Hill	13 cm	----	44 cm
		12 cm	----	39 cm
	Lateral Moraine McCabe Creek			
	a. Lower	10 cm	----	13 cm
		10 cm	----	13 cm
	b. Upper	17 cm	----	41 cm
		13 cm	----	36 cm
	Mean	13.6 cm		39 cm

Table I. Soil and depths of leaching for the moraines in the Ovando Valley.

Sequence of Events
between the
Monture Hill and the Blackfoot River Advances

A cliff situated at the southern foot of Monture Hill (Fig. 4) afforded an opportunity to examine in detail a part of the stratigraphic succession of events from the Monture Hill Advance to the Blackfoot River Advance. This exposure has recently been formed by the Blackfoot River as it shifted its course to the northern part of its floodplain.

The lowest exposed bed in this cliff was till (Fig. 4). It consisted of unsorted material ranging in size from clay to boulders. Boulders over 5 feet (125 cm) were present in much of the material. The position of this till is such that it could have originated from either the Monture or North Fork lobes of ice. Further, the valley at this point would tend to channel ice flow from either glacier toward a more westerly direction. A till fabric (Fig. 5) carried on the till illustrated a strong southwestern orientation of the pebbles. It is not possible to assign a source to this material based on information gathered. Since the axis of flow of the two glaciers was very close at this point, the variations influencing till fabrics (mentioned in the earlier analysis) could easily have determined the alignment.

Overlying the till is 73 inches (184 cm) of gravel (Bed I, Fig. 4). Figure 6 and Table 2A present the results

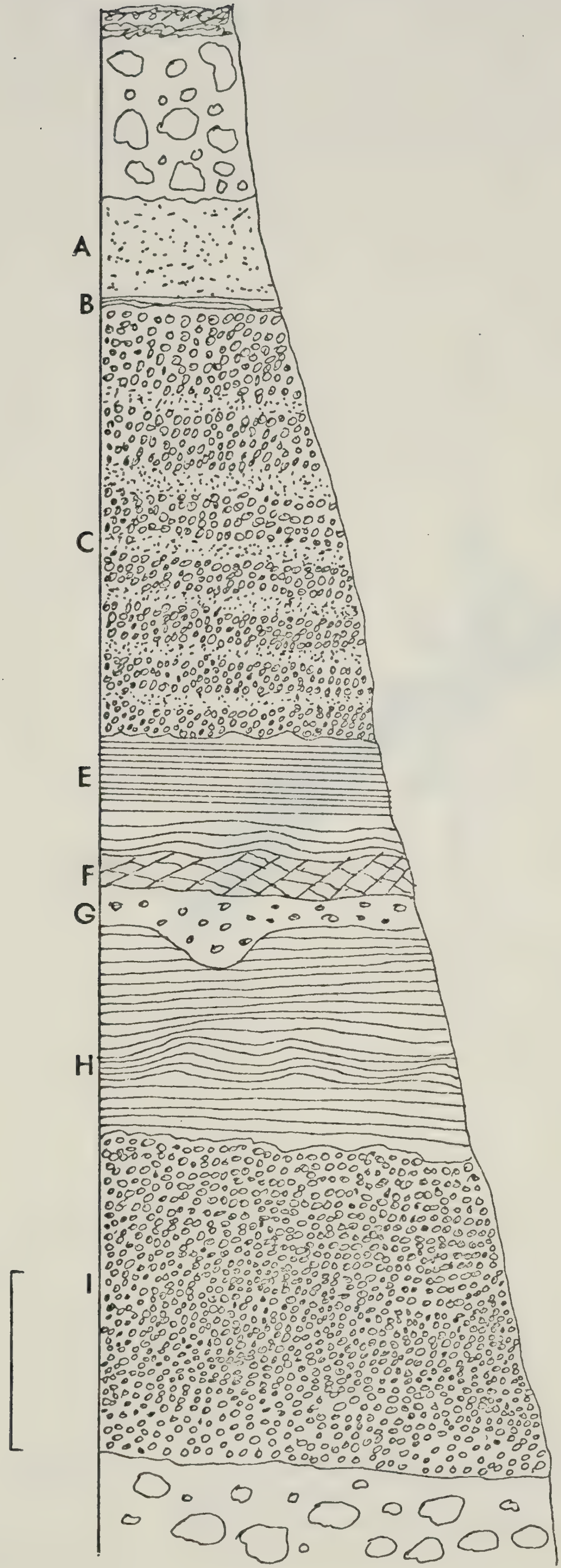


Figure 4. Detail of exposure adjacent to the Blackfoot River south of Monture Hill. Scale at lower equals 4 feet (130 cm.).

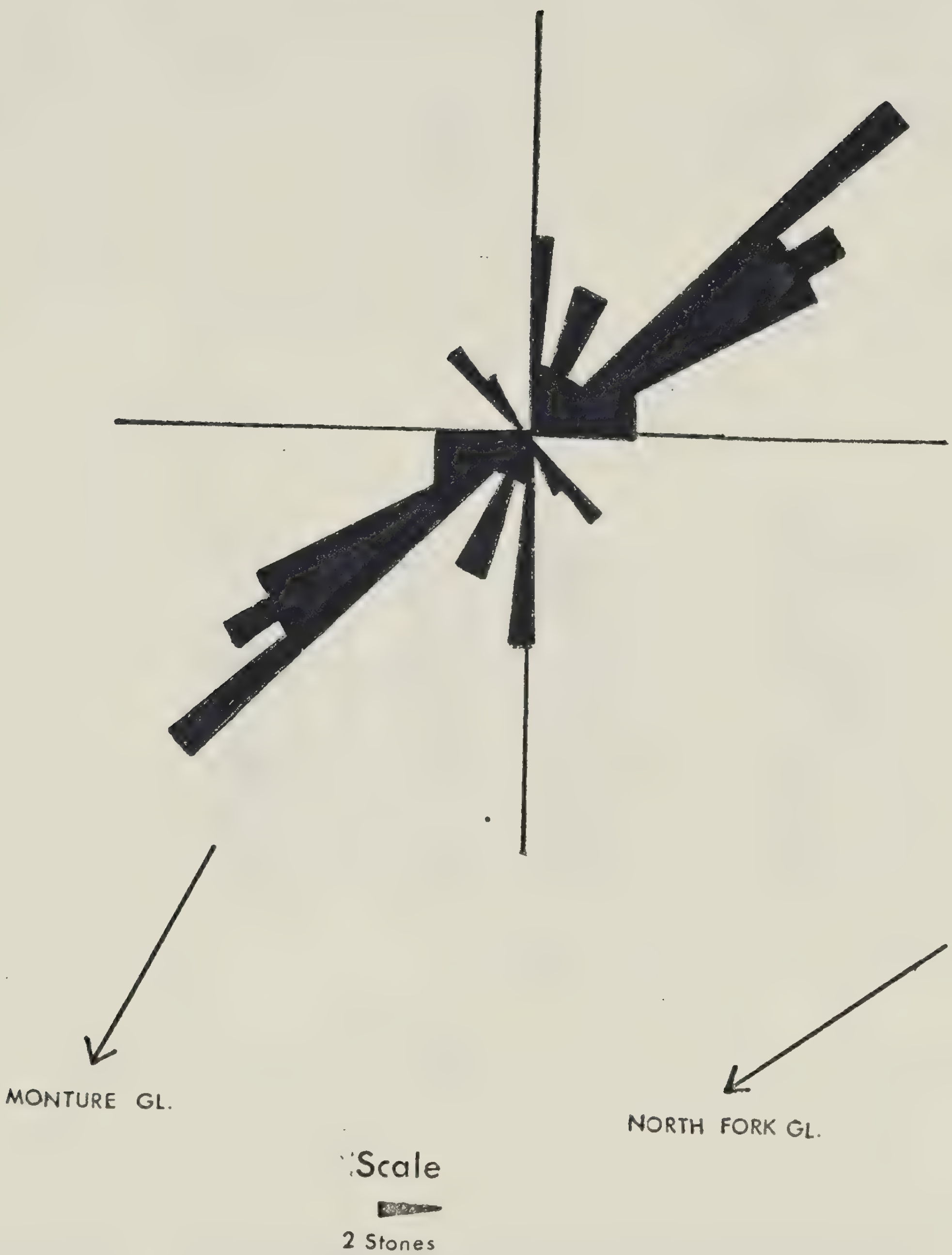


Figure 5. Results of the till fabric analysis conducted on till at the base of cliff south of Monture Hill.

Bed	Graphic Mean (Ø)	Graphic Stand. Dev.
A	6.9	1.65
B	3.7	1.2
C	-1.5	2.05
E	4.7	1.05
F	2.8	.88
G	1.0	3.7
H	3.4	.55
I	3.5	1.31

A

	Mean
177.8 x 152.4 x 121.0	150.6 mm
76.2 x 88.9 x 127.0	97.4 mm
152.4 x 76.2 x 95.2	107.9 mm
108.8 x 114.3 x 127.0	116.7 mm
146.1 x 82.6 x 101.6	110.1 mm
63.5 x 63.5 x 101.6	76.2 mm
88.9 x 177.8 x 114.3	127.0 mm
304.8 x 254.1 x 152.4	237.1 mm
127.0 x 152.4 x 177.9	152.7 mm
228.6 x 177.8 x 177.8	194.7 mm
Overall Mean	137.0 mm

B

Table 2. (A) graphic mean and graphic standard deviations for the beds in figure 4.

(B) size of the ten largest stones (length of the three axes given in mm) in the sample in bed I.

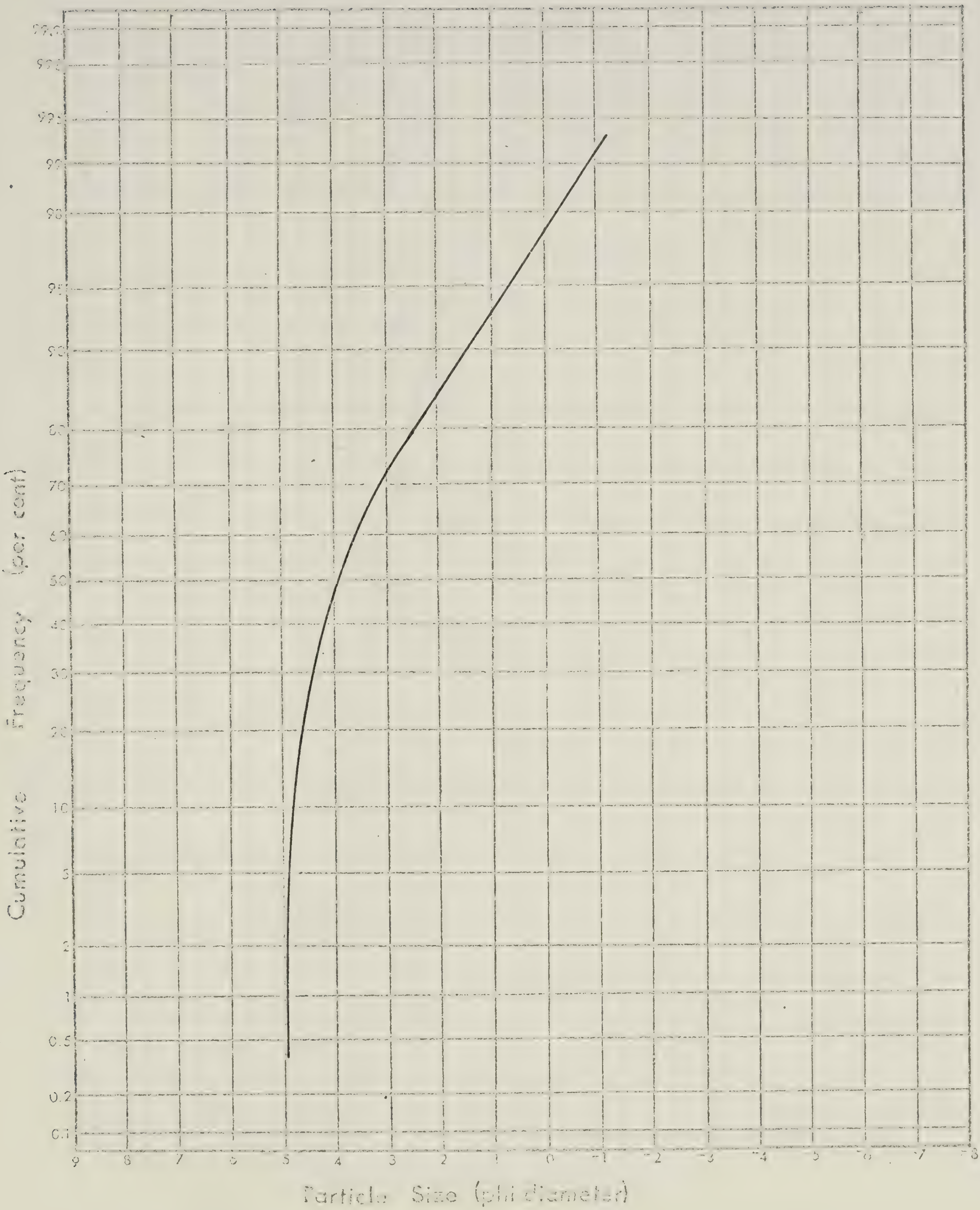


Figure 6. Cumulative frequency curve for bed I.

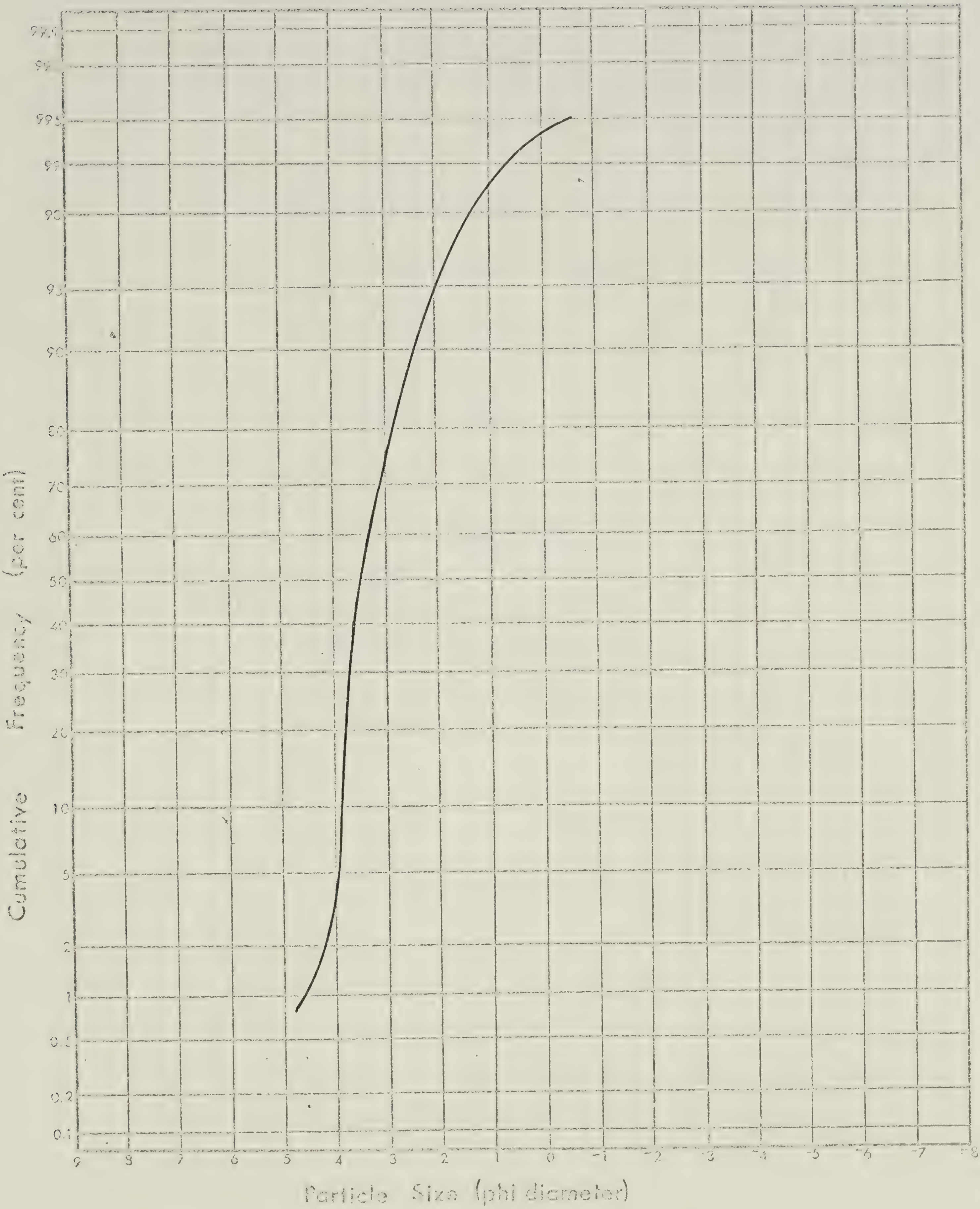


Figure 7. Cumulative frequency curve for bed H.

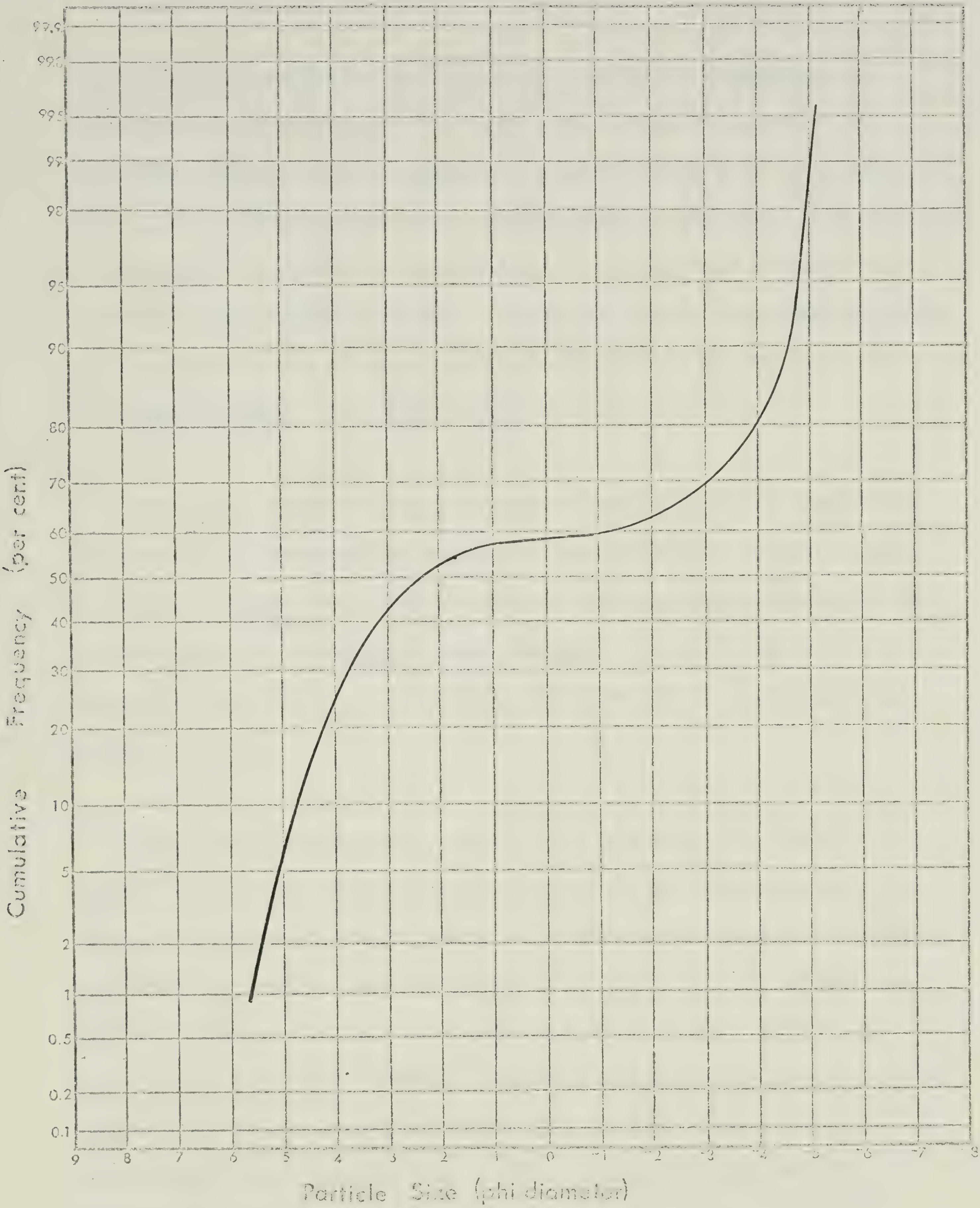


Figure 8. Cumulative frequency curve for bed G.

of the sieve analysis conducted on the bed. Graphic mean and standard deviation are -3.5∅ and 1.31∅, respectively. The first figure illustrates the coarse nature of the material while the latter shows its poorly sorted qualities. It should be pointed out that the mechanical analysis was done on the material finer than 2.38 mm. Table 2B gives the mean diameter of the three axes of the ten largest stones encountered in the examination. The mean value was 137 mm.

The alternating fine and coarse gravels could have been laid down by alternating high and low meltwater runoff periods, the larger material deposited during high flows and the finer material during the low stages. Channel migration is another possibility as is the abandonment of a pro-glacial outwash plain.

The next section (H, Fig. 4) is characterized by four feet (122 cm) of laminated sandy clay. In approximately the center of the bed are ripples of a sinusoidal nature (Jopling and Walker, 1968). An analysis of these ripples, which are about 4 inches (10 cm) in depth and have a wave length of 5.1 inches (13 cm), reveals that the constituent sands have a graphic mean and standard deviation of 3.4∅ and .55∅ respectively, the latter value falling into the moderately sorted class (Fig. 7 and Table 2A).

Bed H indicates a sudden transition from a stream with

a high flow regime to one with low energy. The sands could represent channel fill deposit. The main channel has shifted away from this point and the repeated intrusion of suspended sediment down a sloping surface during times of higher stage flow has formed the bed. Allen (1964) noted a similar structure in the lower Old Red Sandstone of Anglo-Welsh Basin. The ripple forms in the center of the predominantly parallel bedded sands may have been deposited by a slight increase in flow. Jopling and Walker (1968) noted that sinusoidal ripples indicate a minimal amount of bed-load transport by the stream. Also, the sediment must have been partly cohesive since the characteristic asymmetry of ripples is lacking. Cohesive sediments produce asymmetrical ripple forms.

Bed G (Fig. 4) is partially inset in the upper layers of bed H. Sediment comprising this layer is predominantly coarse and fine with the intermediate sizes making up a small part of the overall size range of the sediment. Graphic mean is 1.0Ø and the standard deviation is 3.7Ø (Fig. 8 and Table 2A).

The coarse nature of the material and the shape of the bottom segment of the bed strongly indicate a former channel. A branch of the main stream cutting across the flood plain could erode such a form. It may be that the channel head was previously blocked by a sediment plug and that a higher than normal flow allowed the stream to cut through this plug.

Thus, the stream would be permitted to reoccupy its former course. As indicated by the size of the channel the stream was quite small in volume of flow and may have occupied the channel for only a short period of time during the high flow. Total thickness of the bed is 5.2 inches (13 cm).

Bed F (Fig. 4) is composed of finer material than the underlying layer. Ripples of type A, as described by Jopling and Walker (1968), characterize the form of the bed. Graphic mean and standard deviation are 2,8∅ and .88∅ for this material (Fig. 9 and Table 2A). Total depth is 12.2 inches (31 cm).

A decrease in stream energy is indicated by the moderately sorted nature of the sediments and the relatively fine size as compared to the underlying bed. Movement of material by the stream was mainly by traction. The suspended load was small relative to the bed load, a characteristic of the stream forming this type of ripple (Jopling and Walker, 1968). It is possible that the channel which built the underlying bed was migrating away from this point. Consequently, lateral accretion would be the dominant process operating to build bed F.

The ripples of bed F grade into laminated clay beds of about 48 inches (123 cm) in depth. Graphic mean and standard deviation values for this layer are 4.7∅ and 1.05∅, respectively (Fig. 10 and Table 2A). Although the

clay of bed E fits into the poorly sorted classification, it represents one of the finest sediment beds in the entire section. Varves in the clay range in number from 4 to 29 per inch (2.5 cm).

Energy of the stream that deposited bed E was very low. It may be that a diminishing flow through the channel allowed only the finer material to enter this portion of the flood plain. It could also be that this area was the site of a shallow lagoon and that only water from the higher stages of flow was able to enter the backwater area. This would account for the lamination that characterizes the bed.

Bed C (Fig. 4) illustrates the rapid change to a high energy environment. By the nature of the contact zone, it appears that part of the underlying bed (E) was removed by erosion. The lower portion of bed C is imbedded in the clays and a sharp demarkation is present between the two beds. Graphic mean and standard deviation values for the gravels of bed C are -1.5ϕ and 2.05ϕ, respectively, the former indicating the coarse nature of the sediment and the latter its very poorly sorted characteristics. Throughout the 6 foot (185 cm) extent of the layer, coarse and fine gravels alternate.

Stream migration seems most likely to be responsible for the deposition of these gravels. A sudden surge of water from upstream could cause the main channel to shift suddenly.

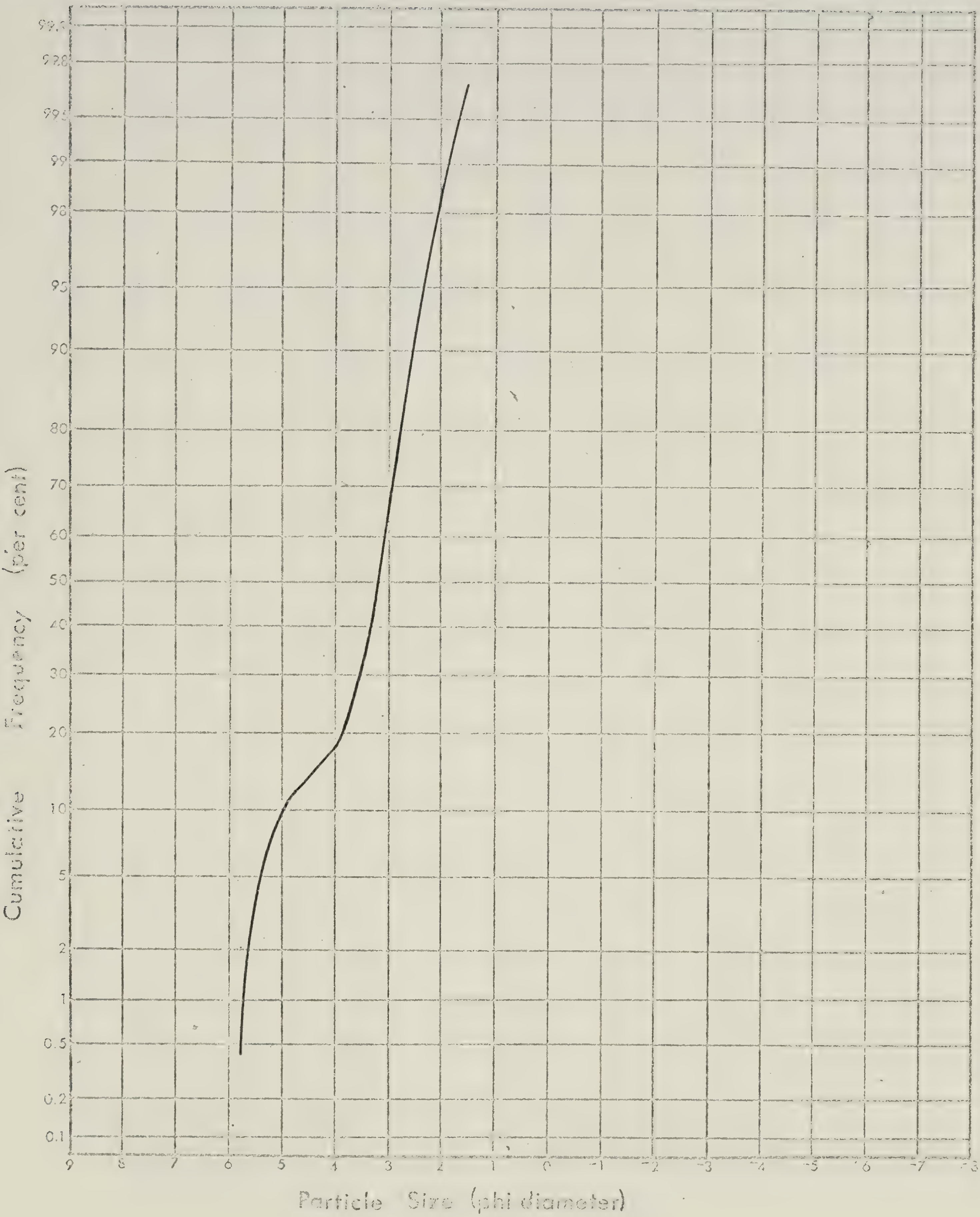


Figure 9. Cumulative frequency curve for bed F.

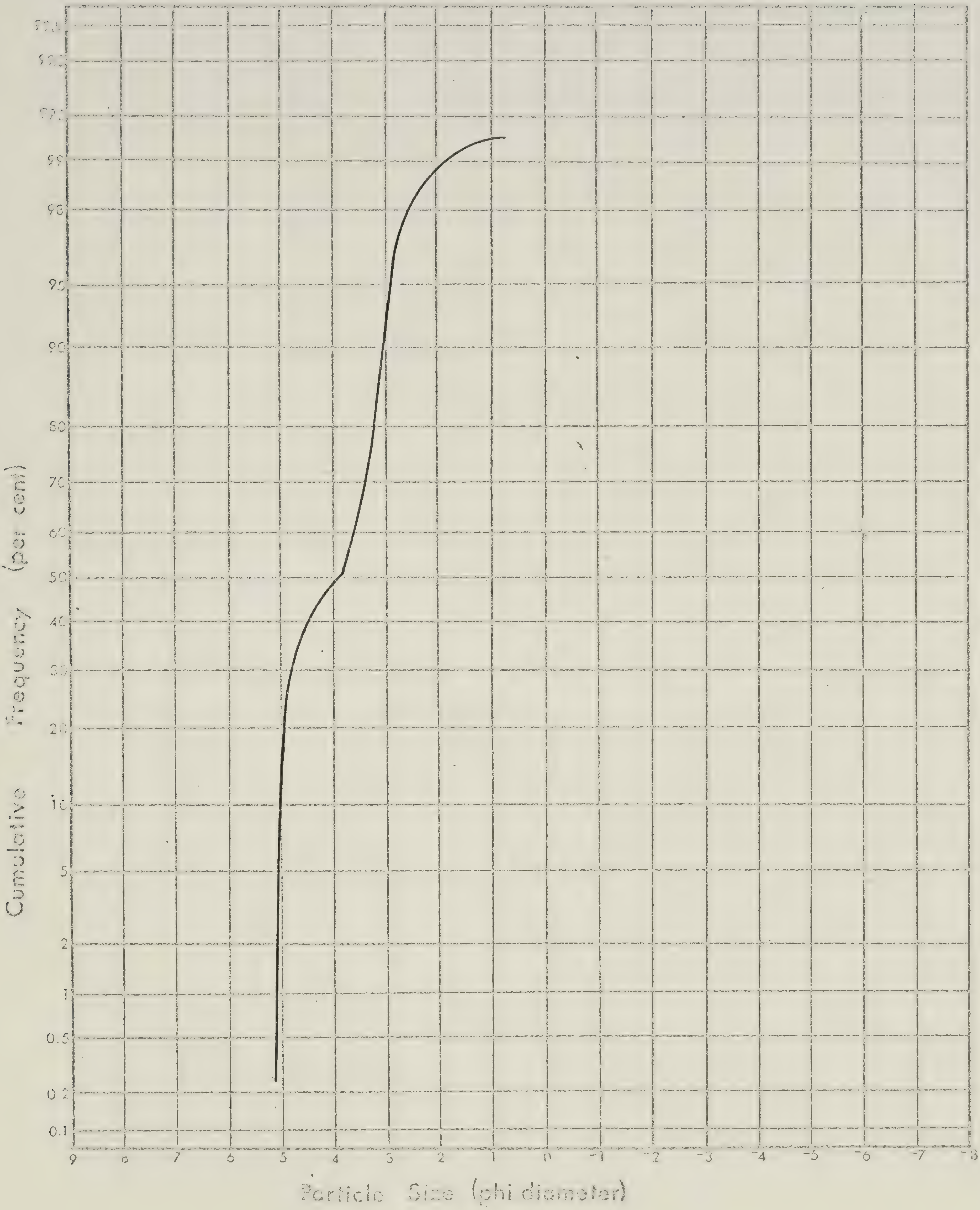


Figure 10. Cumulative frequency curve for bed E.

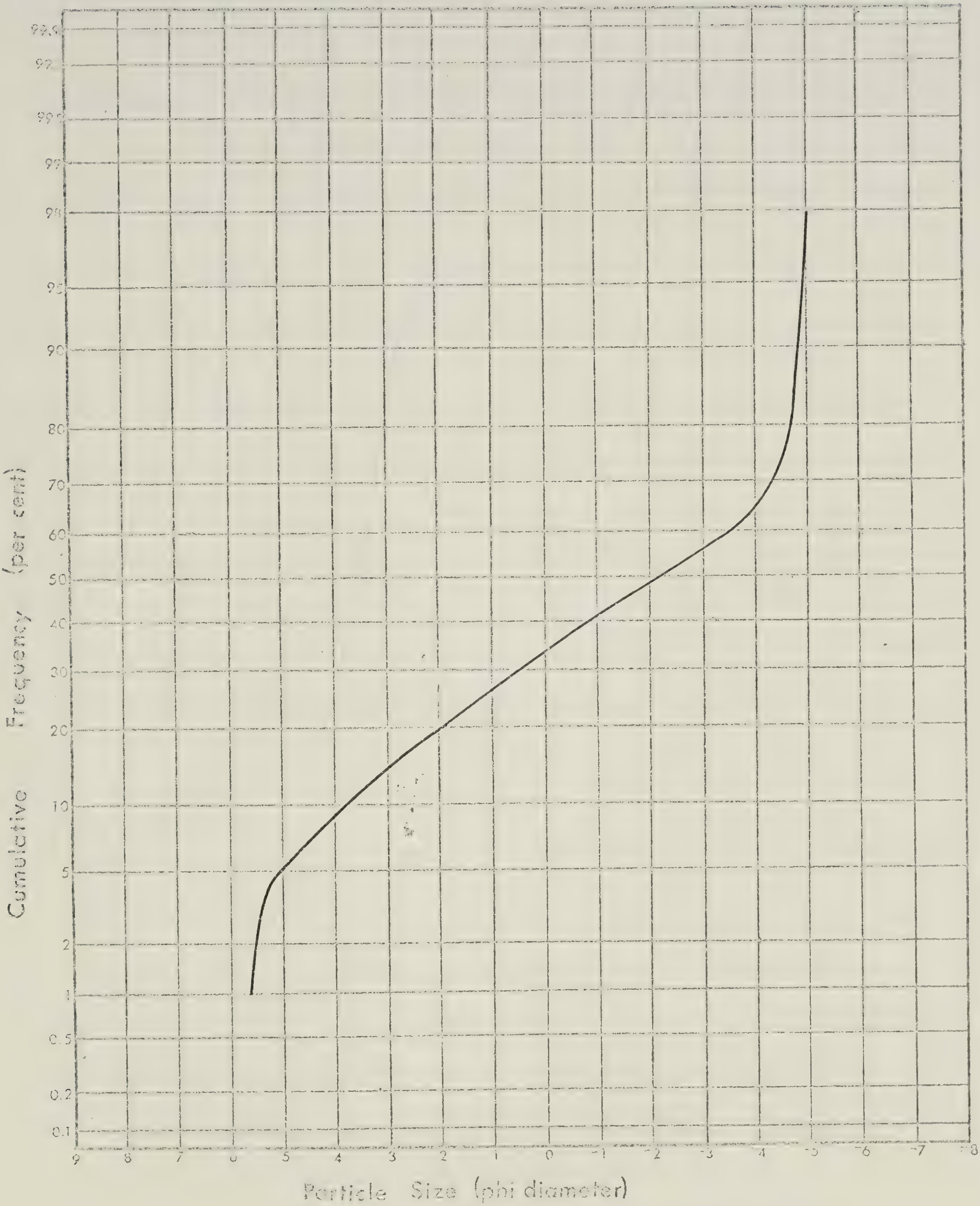


Figure 11. Cumulative frequency curve for bed C.

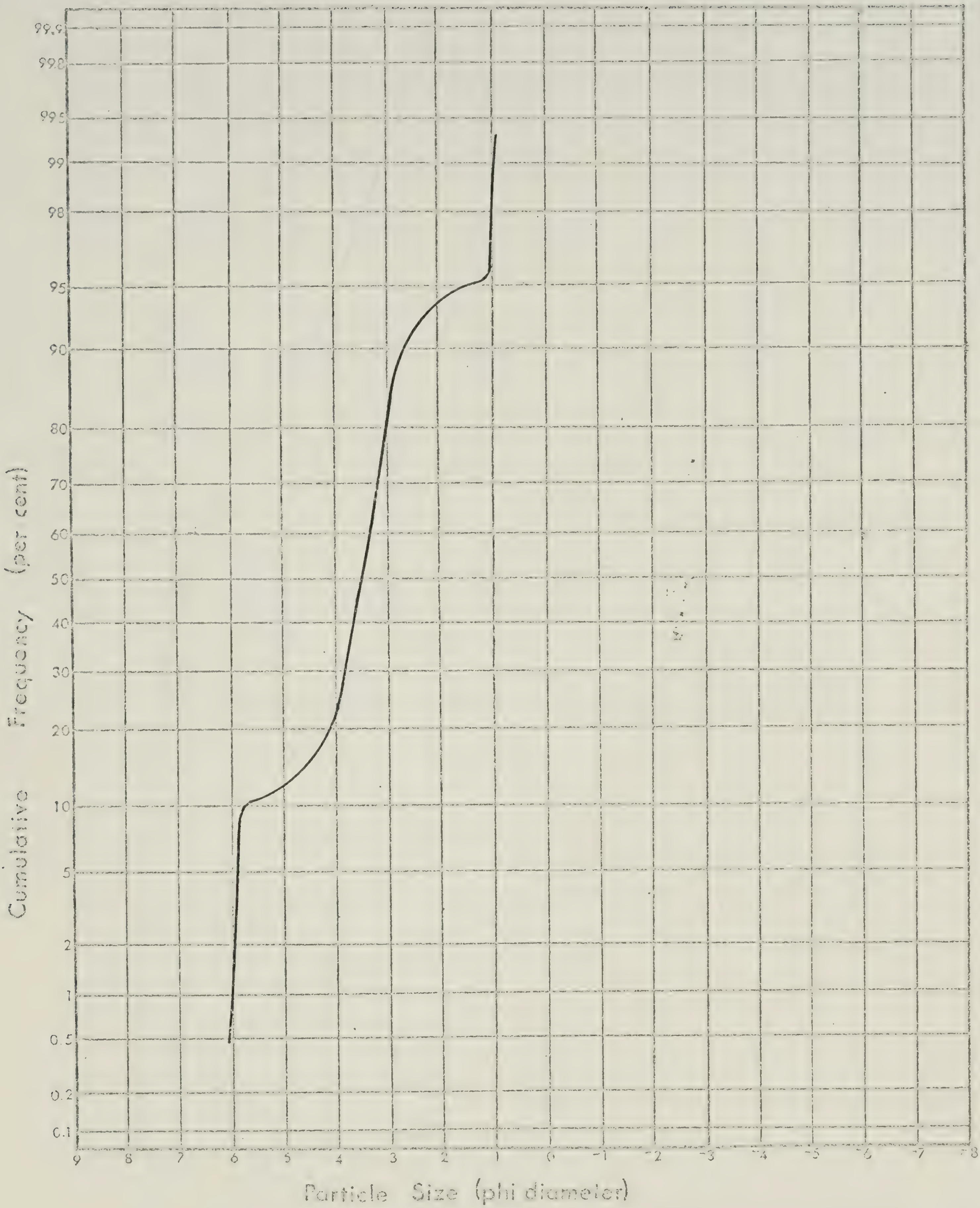


Figure 12. Cumulative frequency curve for bed B.

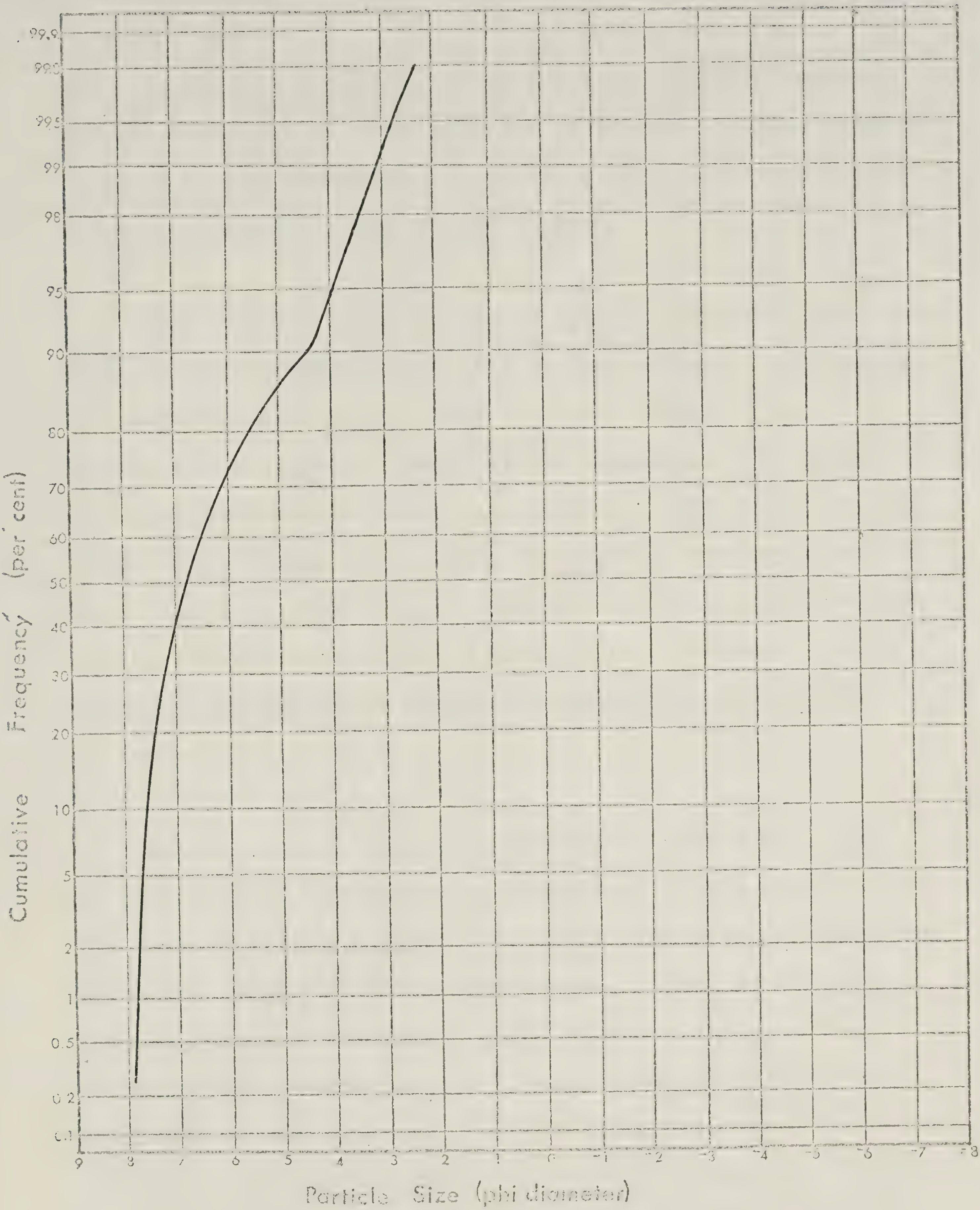


Figure 13. Cumulative frequency curve for bed A.

Once in its new position the stream eroded the top layers of the flood plain. The alternating coarse and fine gravels seem to be lag deposits, the coarse gravel deposited during high flow and the finer at low stages.

Beds B and A (Fig. 4) can be grouped together since they both reflect a change from high to low energy of the stream. Although bed B is only 1 inch (2.5 cm) thick, it can be traced for the entire length of the exposure. Its graphic mean and standard deviation are 3.7∅ and 1.2∅, respectively (Fig. 12 and Table 2A). Bed A is composed of finer material which has a graphic mean of 6.9∅ and a graphic standard deviation of 1.65∅ (Fig. 13 and Table 2A). Both beds are composed of poorly sorted sediments. Thickness of bed A is 42 inches (108 cm).

Again, channel migration could have caused the change in depositional environment. A blocking of the channel at its head by sediment deposited during high water stages could force the stream to change its course. Also, if this was a braided stream at the time, which appears likely by the nature of the underlying bed (coarse material with little bedding), a levee may have been built across one of the branches. Such levees have been noted by Fahnestock (1963) in his study of the braided White River near Mount Rainier in Washington. The lack of bedding and its poorly sorted

nature could also indicate a process of vertical accretion taking place on the floodplain, as described by Allen (1964). However, in view of the abrupt change in the character of the material, it appears that the deposits represent overbank deposition of sediment in an abandoned channel during high flow.

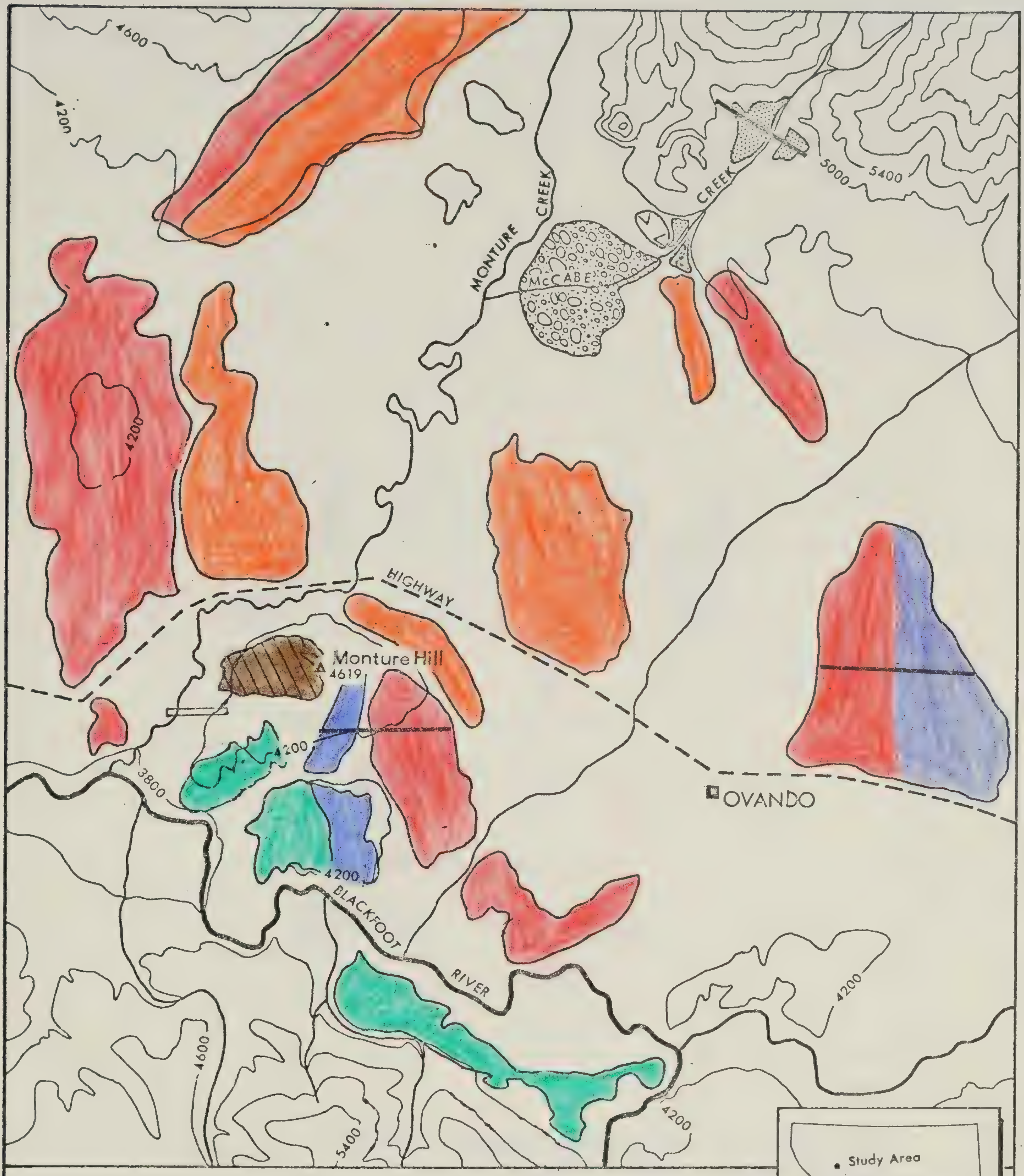
Bed A is topped by till of the Blackfoot River Advance. The hummocky moraines covering this section grade into the lateral moraines of the same advance on the east side of Monture Hill. Depth of the till at this point near the river is quite variable. Immediately above bed A, it is 5 feet (150 cm) thick while farther back from the river the depth increases.

Returning to the two extensive gravel deposits (beds C and I), these deposits may represent advances in either the Monture or North Fork ice lobes. Even if they do not represent gravels deposited directly by streams from the glacier front, they could have been laid down by a migrating channel which shifted its position in response to increased meltwater discharge from farther upstream. The sediment is very poorly sorted, as Doeglas (1962) noted in his study, with a relative rarity of intermediate sizes (2Ø to -4Ø), a characteristic of braided streams. The lack of this size material would indicate a rapidly fluctuating stream. A rapid decrease in discharge, caused by daily meltwater fluctuations, could create the necessary conditions for this type of structure. Further study is needed to determine if these gravels were deposited by meltwater streams, and the source of such streams.

Blackfoot River Advance

Moraines of the Blackfoot River Advance of the former Monture Creek Glacier lie mainly on the flanks of Monture Hill, at the eastern end of the Ovando Valley and bordering the Swan Range, and south of the Blackfoot River next to the northern part of the Garnet Range (Fig. 14). Another moraine which might fit into this category is situated above the Monture Creek Advance moraines and immediately adjacent to Monture Creek where it emerges from the canyon. However, it was not possible to examine this portion because of difficulty of access.

Moraines of this glaciation can be classified into three genetic categories. The lower segment on the eastern side of Monture Hill and the two segments on the western portion are lateral moraines (Figs. 14 and 15). The two western laterals are relatively narrow, whereas the eastern lateral broadens out into a hummocky disintegration moraine. The upper segment on the eastern flank of Monture Hill fits into the terminal category. This moraine overlaps the adjacent Tertiary sediments and continues in a southeasterly direction across the Blackfoot River. Subsequent erosion by the river has destroyed a large portion of it. The segment on the eastern side of Monture Hill has the typical features of a hummocky disintegration moraine. It consists of mounds and depressions that show no alignment, and most of the kettles are partially or wholly filled with alluvium.



GLACIAL DEPOSITS OF OVANDO VALLEY

MONTURE HILL GLACIATION

BLACKFOOT RIVER GLACIATION

Moraine A

Moraine B

MONTURE CREEK GLACIATION

Moraine A

Moraine B

Fan Deposit

Delta

Enlarged Section

A A Profile

Section

N

1 Kil.

1 Mi.

Fig. 14

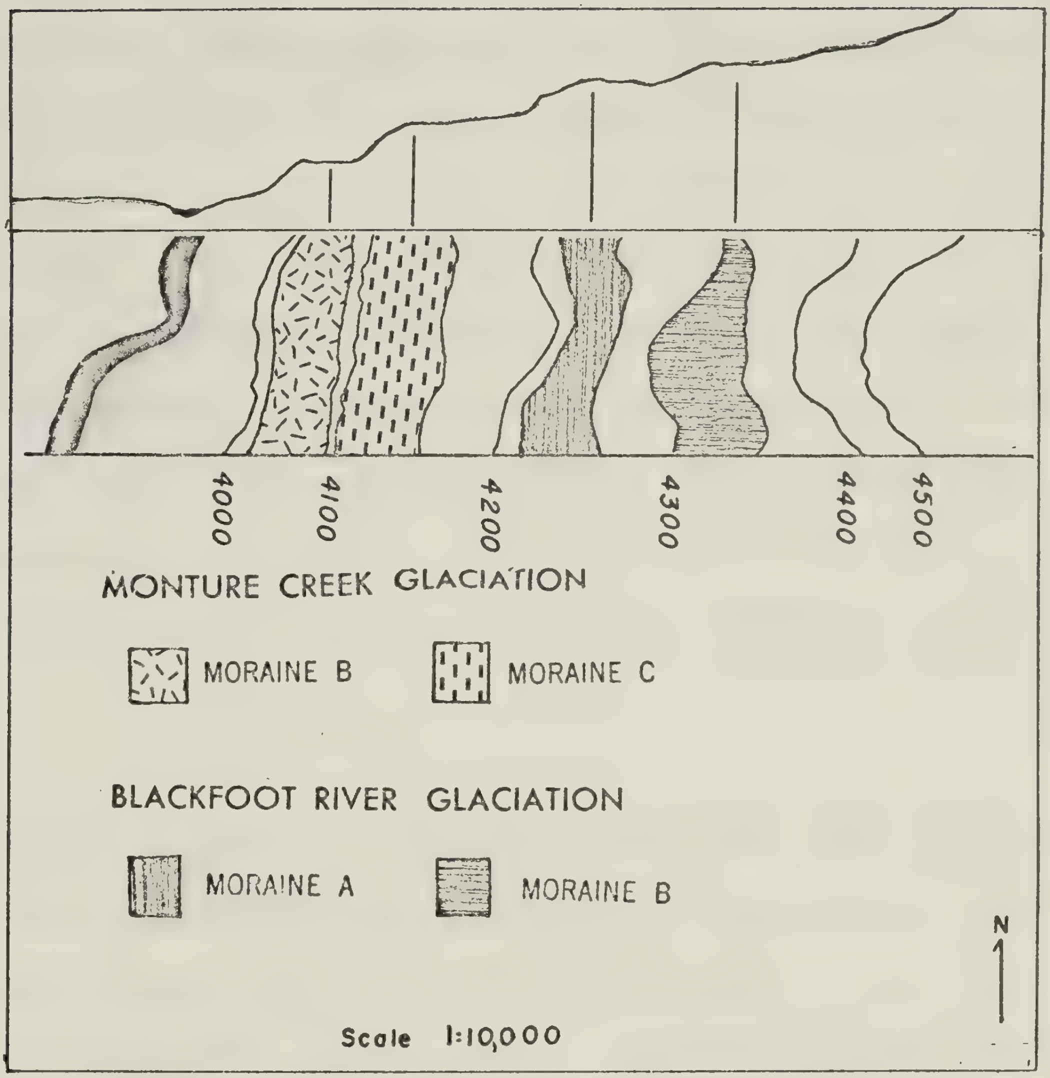


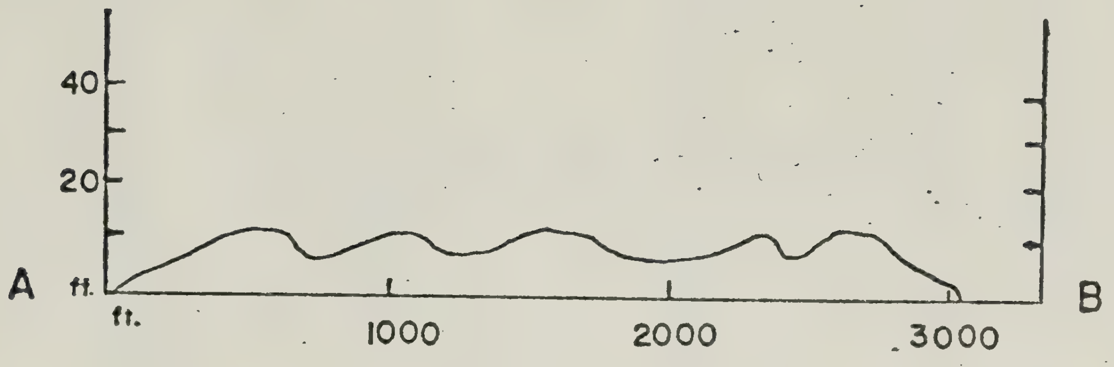
Fig. 15. Lateral moraines on west side of Monture Hill. Upper part of diagram show approximate position of moraines on the hill.

The hummocky disintegration segments of this moraine display the best characteristics that are indicative of relative age. An inspection of aerial photos reveals the subdued nature of the moraine. Filling of the kettles and contemporaneous erosion on the mounds have produced a 20 to 40 foot (6 to 12 m) relief. Figures 16A and 17A show two generalized profiles (based on a 20 foot contour interval map) of this moraine. Typically, the kettles, or former kettles, are flat-floored or gently concave and filled with vegetation (Fig. 18). In one part of the moraine, southeast of Monture Hill, about 25% of the depressions are connected by stream channels. Slope angles for the west-facing portions of the mounds range from 19 to 2 degrees with an overall mean value of 12 degrees (Table 3). Table 1 gives depths of soil and leaching for the moraine.

As indicated in Table I, several values for the B horizon and several leaching depths are missing or approximate. Lack of a B horizon reading was due to the indistinct nature of the boundary between this zone and the underlying parent material. Generally, in this study, B horizon lower boundaries were recognized by the contrast between parent material and B horizon material. However, a gradual gradation between the two zones prevented measurement. Where extreme leaching had occurred, the base of leaching extended below the excavation or exposure and, consequently, only minimum values for depth of leaching could be obtained.

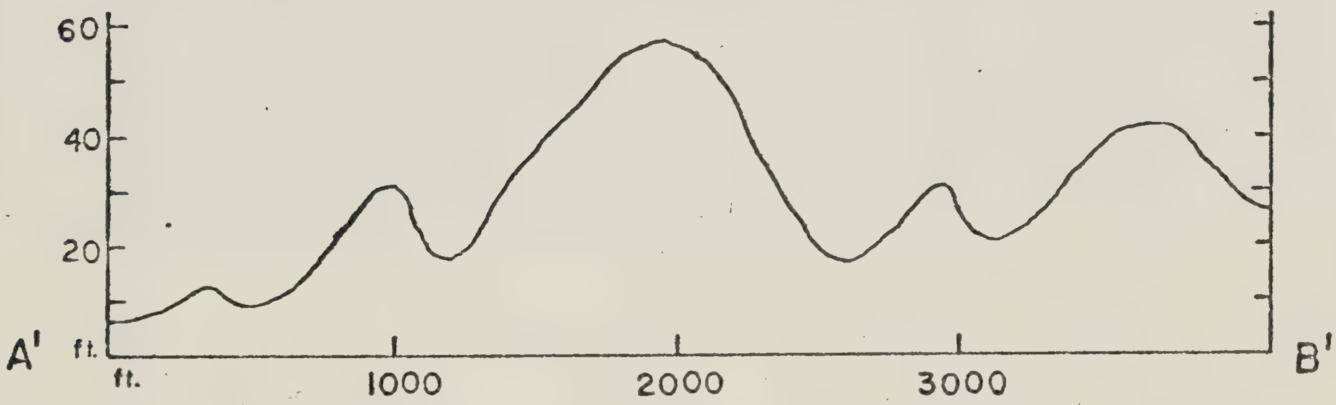
Glacial Advance	Slope Angles (degrees)
Blackfoot River	7, 10, 9, 8, 9, 6, 7, 18, 5, 6, 8, 6, 6, 12, 7, 11, 2, 19, 10, 8, 7, 16, 9, 12, 12, 6, 6, 9 Mean 12°
Monture Creek	21, 16, 20, 23, 21, 18, 26, 24, 21, 29 Mean 21°

Table 3. Angles of west-facing slopes for the Blackfoot River and Monture Creek hummocky disintegration moraines.



A

Vertical Exaggeration—approx. 19X



B

Figure 16. Profiles of Blackfoot River Moraine (A) and the Monture Creek Moraine (B).

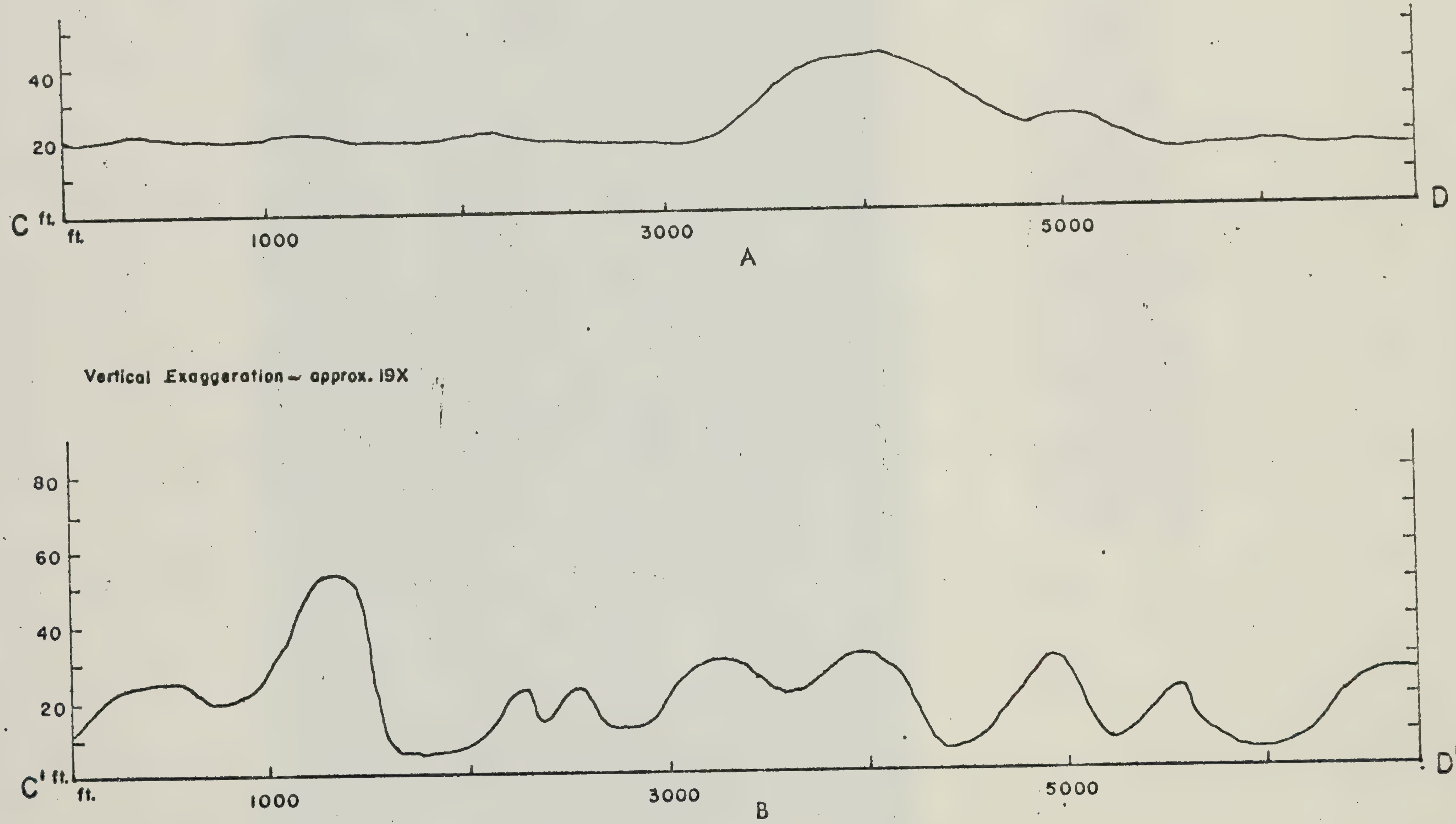

40
20
C ft.
ft.
1000
3000
5000
D
A
Vertical Exaggeration ~ approx. 19X
80
60
40
20
C' ft.
ft.
1000
3000
5000
D'
B

Fig. 17

Figure 18. Hummocky disintegration moraines of the Blackfoot River Advance (foreground) and the Monture Creek Advance (background). The water in the kettles in the foreground is present for only several weeks in the spring of each year.

The two lateral moraines on the west side of Monture Hill have been deeply dissected by axial streams. This situation is in contrast to the lower and younger laterals which have deflected the same intermittent streams. Dissection has reached the point where all that remains of these moraines are discontinuous segments mantling the side of the hill.

A very limited number of argillite boulders were encountered on the Blackfoot River moraines. Those that were found generally had diameters of 2 feet (60 cm) or more. Smaller stones were conspicuously absent. All the larger boulders encountered were weathered to a depth of 2 inches (5 cm). This weathered zone was composed of discolored frost-shattered pieces that supported a thick lichen growth. No relatively unweathered argillite boulders were encountered on this set of moraines.

Two lateral moraines on the east side of Monture Hill indicate the possibility of two stades of glaciation. However, no relative-age data could be found to support such a conclusion. Generally, relative-age techniques have not proven satisfactory in differentiating stades from halts in advance or recession of a glaciation. Lacking stratigraphic evidence, all that can be said at this time is that there may have been two separate stades of Blackfoot River Glaciation in the Ovando Valley.

Monture Creek Advance

Till of the Monture Creek Advance constitutes the youngest and most widespread glacial deposits in the Ovando Valley. Its sharp forms and high relief impart a distinctive characteristic on the topography of the valley floor. The most obvious expression of the moraine is in the hummocky disintegration deposits surrounding Monture Creek from the canyon mouth to the Blackfoot River (Fig. 14). Less spectacular but equally obvious are the lateral and terminal moraines scattered throughout the valley. In the following discussion, the moraines will be discussed by grouping genetically-similar moraines into the same category. First, the hummocky disintegration moraines will be covered, then the terminal, and finally the lateral moraines. Also discussed will be associated features of the last ice advance.

Hummocky Disintegration Moraines. The hummocky disintegration moraines surrounding Monture Creek, and through which Montana Highway 200 was built, are the first notable signs of glaciation to someone entering the valley. Moraines B on the east side of the vally and A immediately west of Monture Creek are the best examples of this type of deposit (Fig. 14). Relief ranges from 40 to 60 feet (12-19 m). The portion of moraine B lying east of the Monture Hill summit and below the Blackfoot deposits has the characteristics of both a lateral and a hummocky disintegration till but is classified in the latter because of its large width relative to its length.

Figure 19. Terminal moraine of Moraine A of the Monture Creek Advance southeast of Monture Hill.

Figure 20. Lateral moraines of Moraine C (left) and Moraine B (right) of the Monture Creek Advance.

Depressions in these moraines contain little or no fill, and there is a noticable lack of interconnecting drainage channels. In late summer, those kettles which are dry reveal a concave profile which is in contrast to the flat-floored nature of the depressions in the Blackfoot River Moraine. Adjacent slopes on the moraines are steep with slope angle values ranging from 16 to 29 degrees with a mean of 21° (Table 3). Figures 16B and 17B illustrate the differences in relief and surface morphology of kettles and mounds in these moraines and the adjacent Blackfoot River deposits.

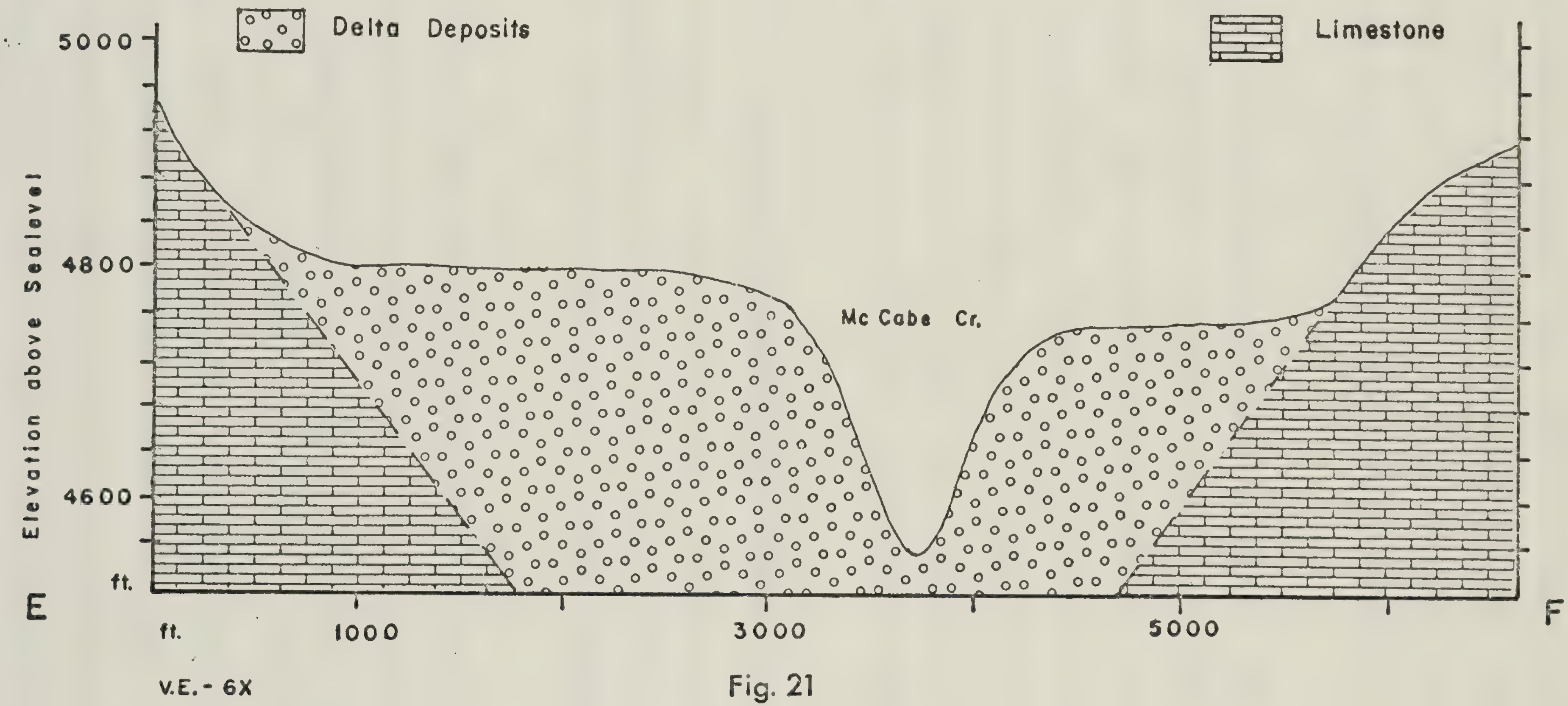
Terminal Moraines. Two well-defined terminal moraines of this glaciation were found in the valley. The largest borders the Blackfoot River southeast of Monture Hill (Fig. 19). Both ends have been partially removed by meltwater from the retreating Monture Glacier and by waters originating in the small canyons of the Swan Range. The other terminal moraine lies at the nothern foot of Monture Hill and extends a short distance around it to a former outwash channel (Fig. 14).

Lateral Moraines. Lateral moraines were found at three localities in the valley - two on the west side of Monture Hill, two bordering McCabe Creek, and one running from Monture Creek down to the hummocky disintegration moraine northwest of Monture Hill. The set on Monture Hill can be traced from the northern part of the hill around and down to the outwash plain bordering the Blackfoot River (Figures 14, 15, and 20). Monture Creek Glacier must have been quite close to its

maximum extent at this point for the moraines descend from an altitude of 4300 feet (1290 m) down to about 50 feet (16 m) above the present floodplain, a drop of 300 feet (90 m) in ½ mile (790 m). Both laterals are similar in character, extending the same distance around Monture Hill and maintaining about the same thickness throughout their extent.

The second set of lateral moraines, on McCabe Creek, were laid down on the west-facing slope of the Swan Range. A one hundred foot (30 m) difference in elevation separates these two moraines as compared to a twenty-five foot (7.5 m) difference for the Monture Hill laterals. During the Monture Creek Advance(s) two extensive deltas were built into water ponded behind the moraines and ice (Fig. 14). When the ice retreated, McCabe Creek cut a narrow V-shaped channel into the deltaic material (Fig. 21).

Today, both deltas remain intact except for the material removed when the stream cut its present channel. The channel divided the deltas into two segments, one on each side of the valley. Gravels which comprise the deltas present a striking contrast to the surrounding bedrock which is limestone. At the time of ice occupation in the valley, waters from McCabe Creek were diverted parallel to the lateral moraines. Two deep ice marginal channels were eroded parallel to the uphill side of the lateral moraines. When the ice melted these channels were abandoned.


Delta Deposits
Limestone
5000
4800
4600
ft.
Elevation above Sealevel
E
F
Mc Cabe Cr.
ft.
1000
3000
5000
V.E. - 6X
Fig. 21

McCabe Creek lateral moraines differ in several respects from their counterparts on Monture Hill. The former are approximately four times larger than the latter, both in aerial extent and volume. Material in the McCabe Creek laterals is more variable ranging from silts and clays to large boulders over 5 feet (150 cm.). The Monture laterals have few stones larger than 6 inches (15 cm). The availability of larger material (bedrock in the canyon) may account for the discrepany in size of constituents of the two sets of moraines.

The lateral moraine extending down from the western side of Monture Canyon merges with hummocky disintegration moraine on the valley floor. It does not form a single linear ridge but appears to be made up of several segments of lateral ridges.

Apparently the lowest member of the McCabe Creek lateral moraine was formed by the last ice lobe to occupy the valley. After the ice withdrew, a large colluvial fan was built by McCabe Creek from material derived from the deltas and moraines (Fig. 14). This cone-shaped deposit remains as a prominant landmark. Any subsequent ice advance into the valley, it would seem, would destroy or modify the fan.

Table 1 presents soil and leaching depths for moraines of the Monture Creek Advance. As can be seen, there are no recordings for the B horizon. This zone was not encountered in the till. In many places the A horizon was so poorly

developed that it was difficult to distinguish it from the parent material. Measurements on the lower McCabe Creek lateral moraine display low values which are significant because soil on this till is presumably the youngest of any developed on moraines in the valley.

Several hundred observations revealed that the thickness of the weathering rind on argillite boulders for the Monture Creek Moraine was very close to 0.12 inch (0.5 cm). None displayed the shattered surface of those found on the Blackfoot River Moraine.

Associated Features. Two prominent physiographic features associated with the stagnation of the Monture Creek Glacier were found in the Ovando Valley. The largest was an esker-like ridge on the east side of the valley and immediately west of the Blackfoot River Moraine. It is about 30 feet (9 m) wide and follows a sinuous course for about 1 mile (1700 meters). On the west side its height above the adjacent outwash plain is 40 feet (12 m) and on its eastern side it rises about 20 feet (6 m) above the alluvial materials. The discrepancy in height on opposite sides is due to filling in of the plain to the east by alluvium carried down by small tributary streams originating in the adjacent mountains. Since no exposures on this ridge were available, a traverse of it was made to gain an idea of its composition. The largest material encountered was rounded stones 6 inches

(15 cm) in diameter. Much smaller sizes of gravel were the dominant materials comprising the ridge. From its shape and composition, it appears that this ridge is an esker.

The second features were to conical hills at the mouth of Monture Canyon. These are shown on figure 14 by the two enclosed contour lines. It does not seem likely that these hills could be composed of bedrock. It is likely that successive glacial advances into the valley would have beveled off such residuals. A surficial examination revealed that these hills were made up of gravels. As in the case of the esker-like ridge, no exposure permitted an examination of the underlying material. From their shape and surficial composition it is concluded that these are kames, formed from sediment washed down by Monture Creek into cracks at the head of the stagnant ice lobe.

Possibility of Several Stades. Again the question arises as to whether the moraines in Ovando Valley resulted from three separate stades of glaciation or from halts in retreat of a single stade. Unlike the Blackfoot River Glaciation, more evidence is available to determine the answer. In this report the moraines have been separated into three groups - A, B, and C (Fig. 14), based on position and continuity. It was felt that by using such a designation, there would be no implication of three separate stades.

Several lines of evidence support the theory of three stades although quantitative measurements cannot be relied on to indicate such. First, the genetic form of several moraines, hummocky disintegration deposits, reveal that the ice front did not retreat but instead stagnated in the valley. Stagnation was due in part to broadening of the ice lobe as it emerged from the canyon mouth, and in part from the meeting of the Monture and the Cottenwood Glaciers. This last point is best illustrated by examining moraine B northwest of Monture Hill. This moraine is situated at a locality where the Monture and Cottenwood Lobes met at approximately right angles. Lateral moraines from both the former glaciers continue from this moraine up their respective canyons.

Secondly, the lower member of the McCabe Creek lateral moraines could have been formed by a readvance of ice into the valley. Its crest axis angle is about 15° south of that of the upper lateral. Such a difference in angle could not be due to a shift in the source of ice as the glacier was restricted to the narrow canyon mouth immediately above this point.

It is possible that a pollen analysis could be conducted on the material at the bottem of the kettles. This technique could provide quantitative evidence to indicate the existence of more than one stade.

Summary of Evidence Indicating Three Episodes of Glaciation

Till situated at or near the summit of Monture Hill was attributed to an early Pleistocene glaciation because of its topographic expression (thin patches) and soil depth of 28 inches (72 cm) for the A horizon and 54 inches (139 cm) for the B horizon. The next set of moraines, the Blackfoot, were distinct from adjacent moraines because of the surface expression, degree of filling of the kettles, truncation of the lateral moraines by erosion, mean slope angle of 12°, soil depth of A and B horizons of 17 inches (44 cm) and 16 inches (41 cm), respectively, and the 2 inch (5 cm) depth of weathering displayed by the argillite boulders.

The youngest till was classified as Monture Creek because of its relief (40 to 60 feet or 12 to 18 m.), relative lack of fill in the kettles, lack of truncation of the lateral moraines, mean soil depth of 5.4 inches (13.6 cm) for the A horizon, general lack of a B horizon, depth of leaching of 15 inches (39 cm), mean slope angle of 21°, and the minor weathering exhibited by argillite boulders.

It should be pointed out again that each of the previous criteria in itself is not evidence of separate advances of ice, but when taken collectively can be used to establish age groups.

CORRELATION

An attempt will be made to correlate the moraines of the Ovando Valley with others in Montana and the Northern Rocky Mountains. Most of the correlation will have to be based on qualitative data since quantitative information is lacking in many studies. When such figures are available a comparison can be made, taking into account the differences resulting from physiographic factors.

Blackwelder's work (1915) represents a classic study in Rocky Mountain glacial morphology and relative-age dating techniques, and today provides the basis for correlation. He distinguished three separate glaciations in the mountains of central Wyoming through the use of time-dependent age characteristics and stratigraphic evidence. The youngest set of moraines were termed Pinedale, those of intermediate age Bull Lake, and the oldest recognizable deposits Buffalo. The first two names have been applied to the glacial stages in the Rocky Mountains. There has been a tendency, especially in recent years, to replace the Buffalo designation with the term Pre Bull Lake to the oldest moraine. The confusion of Pliocene bouldery gravel fans with "Buffalo Till" is the primary cause for abandoning the term (Richmond, 1965, p. 218).

In the Pinedale moraines, Blackwelder noted that lakes and ponds contain little material derived from post glacial

weathering. Boulders are numerous and relatively unweathered. Lateral and terminal moraines remain intact except for the narrow breaching by present-day streams.

His Bull Lake deposits exhibit certain characteristics which separate them from the Pinedale and Buffalo moraines. Surface boulders were less abundant and more weathered. Lakes were rare or absent with peat bogs marking the sites of those which had been filled. Lateral moraines were largely dissected by axial streams in many places.

Richmond has conducted extensive studies on glacial deposits in the Rocky Mountains. In his 1957 study he described the characteristics of pre-Wisconsin (pre-Bull Lake) till in selected areas. He noted that these moraines tend to be sheetlike in form and lack morainal topography. The surface of the till is smooth and has few exposed boulders. It commonly caps interstream divides and lies above and beyond the outer limits of younger moraines. Soils on the till are well-developed ranging from four feet (1.2 m) to ten feet (3 m) in depth.

In a later article Richmond (1965) expands somewhat on the surficial features of the three moraine groups. The Bull Lake till have soils with B horizons of 12 to 47 inches (0.3 to 1.2 m) thick that show a yellowish brown color in the northern latitudes. Soils on Pinedale tills have B horizons 12 to 24 inches (0.3 m to 0.6 m) thick.

Horberg (1956) made several observations of depth of leaching on the three moraine groups in Glacier National Park, Montana. The surface of the Wisconsin moraines (Pinedale) were leached to a depth of 24 inches (62 cm). Early Wisconsin moraines (Bull Lake) displayed an average leaching depth of 64 inches (164 cm) while the Kennedy moraine (pre Bull Lake) had a maximum known depth of leaching of 57 feet (18 m).

Alden (1953) who conducted the most extensive survey of glacial deposits in Montana gives no quantitative and very little qualitative data to substantiate his differentiation of moraines. The pre Wisconsin drift he recognized was described as being "considerably weathered" and capping bedrock spurs. In other areas it consisted only of scattered erratics. He mapped what he believed to be Iowan or Illinoin (Bull Lake) drift which bordered the Blackfoot River southwest of Ovando and east of Monture Hill. Other moraine closer to the mouth of Monture Canyon was placed in the Wisconsin category. The only description he gives of the Wisconsin moraines is that they have a strongly defined knob and kettle topography.

Holmes and Moss (1955) examined glacial morphology in the southwestern part of the Wind River Mountains in Wyoming near Blackwelder's study area. They used the same names applied by Blackwelder to designate the morainal groups. Buffalo deposits were described by them as low, formless mounds with deeply weathered and stained surficial boulders and on which

erosional agencies had brought about nearly complete wastage of the moraines. Bull Lake moraines were described as having surface boulders only moderately weathered and on which only a moderate amount of relief reduction had taken place. Pinedale moraines showed slight wastage and weathering of surface boulders and had steep-fronted margins.

In his study of the Madison Range in south-central Montana, Giles (1970) found that soil depth was the most useful criteria in establishing the ages of moraines. The late Bull Lake stade moraines had 40 to 60 inches (103-154 cm), the Pinedale early stade 24 to 33 inches (61-84 cm), the Pinedale middle stade 11 to 19 inches (28-48 cm), and the Pinedale late stade 5 to 7 inches (13-16 cm) of soil (Giles, 1970, p. 52).

Pierce (1970, p. 105) gives additional evidence for moraine differentiation based on his work in northern Yellowstone National Park. He states that Bull Lake moraines show considerably more modification by post glacial weathering agencies than do the Pinedale moraines (filling of kettles, dissection, etc.). Soils on the Bull Lake Till are generally 3-4 feet thick (91-122 cm) with moderately developed B horizon structure over an interval greater than 1 foot (31 cm). Soils on the Pinedale moraine are 1-3 feet thick (31-92 cm) and display paler colors. His weathering of surface boulder measurments were made on the <u>underside</u> of dacitic intrusive cobbles and ranged from 1mm in thickness for stones on the

Pinedale crests and about 2-4 mm on Bull Lake moraine crests, increasing in thickness from the younger to the older Bull Lake deposits.

The above studies by no means represent a complete list of work done on Rocky Mountain chronology but they do give the basic characteristics of Pleistocene moraines. Adequate quantitative and qualitative data are given so that a tentative correlation can be made of the Ovando Valley glacial deposits with other moraines in the northern Rocky Mountains.

The Buffalo or pre Bull Lake moraines form sheet deposits on spurs and interstream divides well above the younger moraines. In the Ovando Valley, the Monture Hill would appear to correspond to these tills. It has no recognizable surface form. It is situated above the Blackfoot River moraines but the vertical distance is not nearly as great as in other areas for comparable tills. Presumably, such discrepancy in heights is due to the comparatively small size of the former Monture Glacier and the relatively wide valley.

Depth of leaching according to Horberg (1956) was at least 57 feet (18 m) on pre Bull Lake tills in Glacier National Park. No cross section permitted a measurement of such a depth on Monture Hill but it is believed that the leaching depth would be considerably less because of the relatively dry climate. One factor that could be compared more directly with the

findings of other workers, although climate is still an important factor, wassoil depth. Richmond (1965) measured soil depth on pre Bull Lake moraines as being 4-10 feet (112-315 cm) in depth. Soil depth on Monture Hill was slightly over 6 feet (210 cm), deeper than any other soils encountered in the Ovando Valley, and comparable to Richmond's findings.

Some writers, as previously mentioned, found that the only indication of the Buffalo or pre Bull Lake till was scattered erratics. The thick accumulation of rounded boulders on the crest of Monture Hill is comparable to this situation. All the finer material has been removed, leaving these erratics resting unconformably on quartzite bedrock.

The chief characteristic of the Bull Lake moraines are fewer surface boulders (than Pinedale till), absence or rarity of lakes, dissection by streams, depths of leaching of 64 inches (164 cm), soils 12 to 47 inches (31-120 cm) thick, and smaller surface relief. From observations made on the Blackfoot River moraines it is evident that this till could be classified as Bull Lake in age. Lakes are rare with flat-floored depressions replacing them. Relief is moderate with low mean slope angles (12^{o}). Mean values for the A and B soil horizons are 17 and 16 inches (44-41 cm), respectively. Depth of leaching ranged from 30 inches (77 cm) to over 6 feet (185 cm). The values for the last two criteria are lower for the Ovando Valley because of the

lower precipitation. Surface boulders display more weathering (than on the Monture Creek Till) where argillite has been shattered and stained to depths of 2 inches (5 cm) or more. Lateral moraines are extremely dissected as was found to be the case in other Bull Lake tills.

Distinctive features which characterize the Pinedale moraines include numerous unweathered surface boulders, relatively large relief with steep slopes, soil depth of 12-24 inches (31-61 cm), leaching depths of 24 inches (61 cm), and lack of dissection of lateral moraines by axial streams. All these characteristics can be found in the Monture Creek moraines. Soil and leaching depths are shallow (5.4 and 15 inches - 13.6 cm and 39 cm, respectively) with a B horizon lacking. Lateral moraines on the west side of Monture Hill are not breached by axial streams. Kettles contain little or no fill and adjacent slopes are steep (21^{o}).

In conclusion, the Monture Hill drift is assigned to the pre Bull Lake age group, the Blackfoot River moraine to the Bull Lake age group, and the Monture Creek drift to the Pinedale age group.

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